Field, C. B., Barros, V. R., Mach, K. J., Mastrandrea, M. D., Aalst, M. V., Adger, W. N., ... Yohe, G. W. (2015). Technical Summary. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, ... L. L. White (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Vol. 1, pp. 35-94). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
Publisher's PDF, also known as Version of record

TS

Technical Summary

Prepared under the leadership of the Working Group II Bureau:

Amjad Abdulla (Maldives), Vicente R. Barros (Argentina), Eduardo Calvo (Peru), Christopher B. Field (USA), José M. Moreno (Spain), Nirivololona Raholijao (Madagascar), Sergey Semenov (Russian Federation), Neville Smith (Australia)

Coordinating Lead Authors:

Christopher B. Field (USA), Vicente R. Barros (Argentina), Katharine J. Mach (USA), Michael D. Mastrandrea (USA)

Lead Authors:

Maarten K. van Aalst (Netherlands), W. Neil Adger (UK), Douglas J. Arent (USA), Jonathon Barnett (Australia), Richard A. Betts (UK), T. Eren Bilir (USA), Joern Birkmann (Germany), JoAnn Carmin (USA), Dave D. Chadee (Trinidad and Tobago), Andrew J. Challinor (UK), Monalisa Chatterjee (USA/India), Wolfgang Cramer (Germany/France), Debra J. Davidson (Canada), Yuka Otsuki Estrada (USA/Japan), Jean-Pierre Gattuso (France), Yasuaki Hijioka (Japan), Ove Hoegh-Guldberg (Australia), He-Qing Huang (China), Gregory E. Insarov (Russian Federation), Roger N. Jones (Australia), R. Sari Kovats (UK), Joan Nymand Larsen (Iceland), Iñigo J. Losada (Spain), José A. Marengo (Brazil), Roger F. McLean (Australia), Linda O. Mearns (USA), Reinhard Mechler (Germany/Austria), John F. Morton (UK), Isabelle Niang (Senegal), Taikan Oki (Japan), Jane Mukarugwiza Olwoch (South Africa), Maggie Opondo (Kenya), Elvira S. Poloczanska (Australia), Hans-O. Pörtner (Germany), Margaret Hiza Redsteer (USA), Andy Reisinger (New Zealand), Aromar Revi (India), Patricia Romero-Lankao (Mexico), Daniela N. Schmidt (UK), M. Rebecca Shaw (USA), William Solecki (USA), Dáithí A. Stone (Canada/South Africa/USA), John M.R. Stone (Canada), Kenneth M. Strzepek (UNU/USA), Avelino G. Suarez (Cuba), Petra Tschakert (USA), Riccardo Valentini (Italy), Sebastián Vicuña (Chile), Alicia Villamizar (Venezuela), Katharine E. Vincent (South Africa), Rachel Warren (UK), Leslie L. White (USA), Thomas J. Wilbanks (USA), Poh Poh Wong (Singapore), Gary W. Yohe (USA)

Review Editors:

Paulina Aldunce (Chile), Jean Pierre Ometto (Brazil), Nirivololona Raholijao (Madagascar), Kazuya Yasuhara (Japan)

This Technical Summary should be cited as:

Field, C.B., V.R. Barros, K.J. Mach, M.D. Mastrandrea, M. van Aalst, W.N. Adger, D.J. Arent, J. Barnett, R. Betts, T.E. Bilir, J. Birkmann, J. Carmin, D.D. Chadee, A.J. Challinor, M. Chatterjee, W. Cramer, D.J. Davidson, Y.O. Estrada, J.-P. Gattuso, Y. Hijioka, O. Hoegh-Guldberg, H.Q. Huang, G.E. Insarov, R.N. Jones, R.S. Kovats, P. Romero-Lankao, J.N. Larsen, I.J. Losada, J.A. Marengo, R.F. McLean, L.O. Mearns, R. Mechler, J.F. Morton, I. Niang, T. Oki, J.M. Olwoch, M. Opondo, E.S. Poloczanska, H.-O. Pörtner, M.H. Redsteer, A. Reisinger, A. Revi, D.N. Schmidt, M.R. Shaw, W. Solecki, D.A. Stone, J.M.R. Stone, K.M. Strzepek, A.G. Suarez, P. Tschakert, R. Valentini, S. Vicuña, A. Villamizar, K.E. Vincent, R. Warren, L.L. White, T.J. Wilbanks, P.P. Wong, and G.W. Yohe, 2014: Technical summary. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 35-94.

Contents

ASSESSING AND MANAGING THE RISKS OF CLIMATE CHANGE

Human interference with the climate system is occurring (WGI AR5 SPM Section D.3; WGI AR5 Sections 2.2, 6.3, 10.3 to 10.6, 10.9). Climate change poses risks for human and natural systems (Figure TS.1). The assessment of impacts, adaptation, and vulnerability in the Working Group II contribution to the IPCC's Fifth Assessment Report (WGII AR5) evaluates how patterns of risks and potential benefits are shifting due to climate change. It considers how impacts and risks related to climate change can be reduced and managed through adaptation and mitigation. The report assesses needs, options, opportunities, constraints, resilience, limits, and other aspects associated with adaptation. It recognizes that risks of climate change will vary across regions and populations, through space and time, dependent on myriad factors including the extent of adaptation and mitigation.

Climate change involves complex interactions and changing likelihoods of diverse impacts. A focus on risk, which is new in this report, supports decision making in the context of climate change and complements other elements of the report. People and societies may perceive or rank risks and potential benefits differently, given diverse values and goals.

Compared to past WGII reports, the WGII AR5 assesses a substantially larger knowledge base of relevant scientific, technical, and socioeconomic literature. Increased literature has facilitated comprehensive assessment across a broader set of topics and sectors, with expanded coverage of human systems, adaptation, and the ocean. See Box TS.1.

Section A of this summary characterizes observed impacts, vulnerability and exposure, and adaptive responses to date. Section B examines future risks and potential benefits across sectors and regions, highlighting where choices matter for reducing risks through mitigation and adaptation. Section C considers principles for effective adaptation and the broader interactions among adaptation, mitigation, and sustainable development.

Box TS.2 defines central concepts. To convey the degree of certainty in key findings, the report relies on the consistent use of calibrated uncertainty language, introduced in Box TS.3. Chapter references in brackets indicate support for findings, figures, and tables in this summary.

A: OBSERVED IMPACTS, VULNERABILITY, AND ADAPTATION IN A COMPLEX AND CHANGING WORLD

This section presents observed effects of climate change, building from understanding of vulnerability, exposure, and climate-related hazards as determinants of impacts. The section considers the factors, including development and non-climatic stressors, that influence vulnerability and

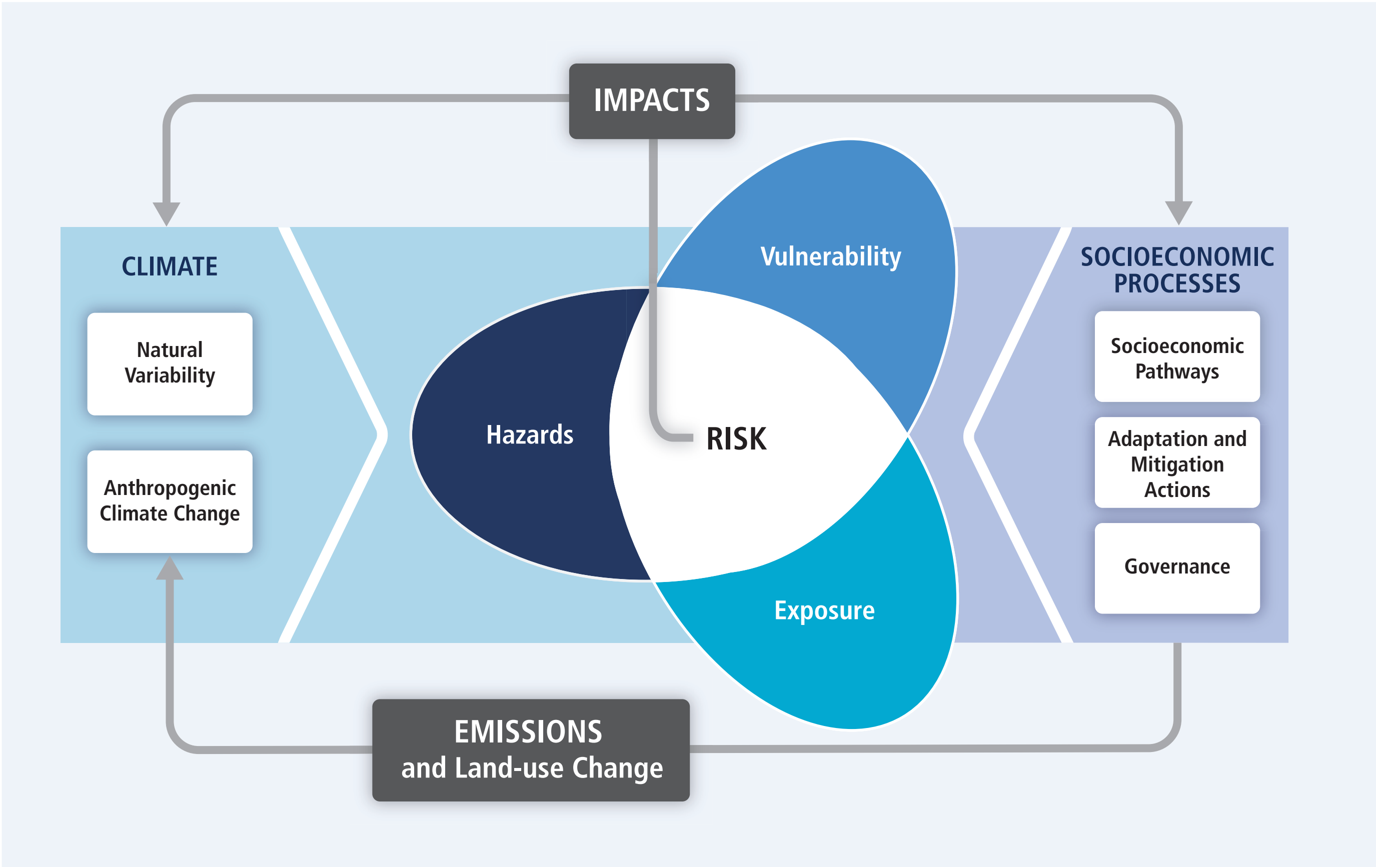
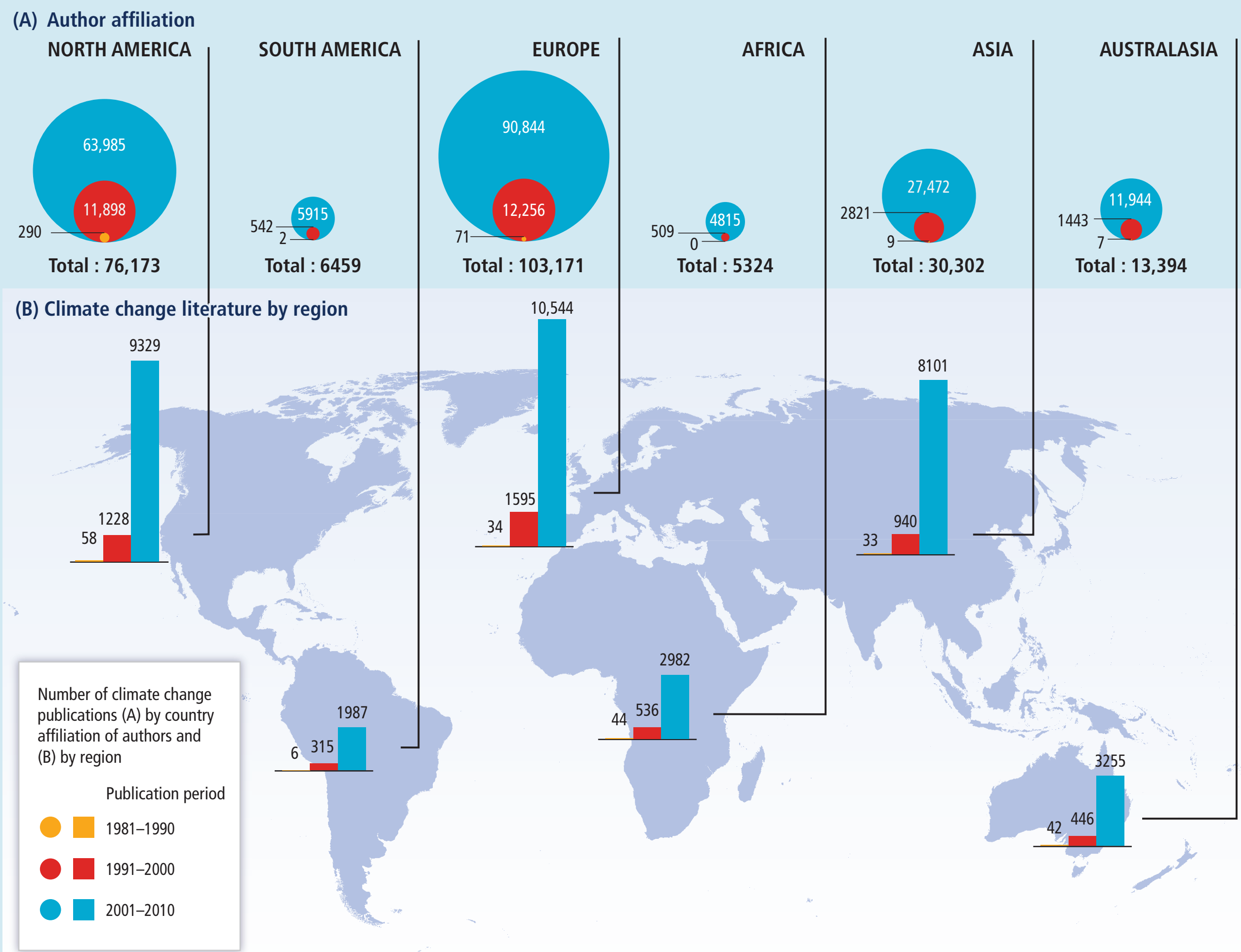


Figure TS.1 | Illustration of the core concepts of the WGII AR5. Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left) and socioeconomic processes including adaptation and mitigation (right) are drivers of hazards, exposure, and vulnerability. [19.2, Figure 19-1]

Box TS.1 | Context for the Assessment

For the past 2 decades, IPCC's Working Group II has developed assessments of climate change impacts, adaptation, and vulnerability. The WGII AR5 builds from the WGII contribution to the IPCC's Fourth Assessment Report (WGII AR4), published in 2007, and the *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX), published in 2012. It follows the Working Group I contribution to the AR5 (WGI AR5). The WGII AR5 is presented in two parts (Part A: Global and Sectoral Aspects, and Part B: Regional Aspects), reflecting the expanded literature basis and multidisciplinary approach, increased focus on societal impacts and responses, and continued regionally comprehensive coverage. [1.1 to 1.3]

The number of scientific publications available for assessing climate change impacts, adaptation, and vulnerability more than doubled between 2005 and 2010, with especially rapid increases in publications related to adaptation, allowing for a more robust assessment that supports policymaking (*high confidence*). The diversity of the topics and regions covered has similarly expanded, as has the geographic distribution of authors contributing to the knowledge base for climate change assessments (Box TS.1 Figure 1). Authorship of climate change publications from developing countries has increased, although it still represents a small fraction of the total. The unequal distribution of publications presents a challenge to the production of a comprehensive and balanced global assessment. [1.1, Figure 1-1]



Box TS.1 Figure 1 | Number of climate change publications listed in the Scopus bibliographic database. (A) Number of climate change publications in English (as of July 2011) summed by country affiliation of all authors of the publications and sorted by region. Each publication can be counted multiple times (i.e., the number of different countries in the author affiliation list). (B) Number of climate change publications in English with individual countries mentioned in title, abstract, or key words (as of July 2011) sorted by region for the decades 1981–1990, 1991–2000, and 2001–2010. Each publication can be counted multiple times if more than one country is listed. [Figure 1-1]

Continued next page →

Box TS.1 (continued)

Adaptation has emerged as a central area in climate change research, in country-level planning, and in implementation of climate change strategies (*high confidence*). The body of literature, including government and private sector reports, shows an increased focus on adaptation opportunities and the interrelations between adaptation, mitigation, and alternative sustainable pathways. The literature shows an emergence of studies on transformative processes that take advantage of synergies between adaptation planning, development strategies, social protection, and disaster risk reduction and management. [1.1]

As a core feature and innovation of IPCC assessment, major findings are presented with defined, calibrated language that communicates the strength of scientific understanding, including uncertainties and areas of disagreement (Box TS.3). Each finding is supported by a traceable account of the evaluation of evidence and agreement. [1.1, Box 1-1]

Box TS.2 | Terms Central for Understanding the Summary

Central concepts defined in the WGII AR5 glossary and used throughout the report include the following terms. Reflecting progress in science, some definitions differ in breadth and focus from the definitions used in the AR4 and other IPCC reports.

Climate change: Climate change refers to 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 changes in the composition of the atmosphere or in land use. Note that the 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.

Hazard: The potential occurrence of a natural or human-induced physical event or trend or physical impact 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. In this report, the term *hazard* usually refers to climate-related physical events or trends or their physical impacts.

Exposure: 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.

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Impacts: Effects on natural and human systems. In this report, the term *impacts* is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as *consequences* and *outcomes*. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.

Continued next page →

Box TS.2 (continued)

Risk: The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard (see Figure TS.1). In this report, the term *risk* is used primarily to refer to the risks of climate-change impacts.

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Incremental adaptation: Adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale.

Transformational adaptation: Adaptation that changes the fundamental attributes of a system in response to climate and its effects.

Transformation: A change in the fundamental attributes of natural and human systems.

Resilience: The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

exposure, evaluating the sensitivity of systems to climate change. The section also identifies challenges and options based on adaptation experience, looking at what has motivated previous adaptation actions in the context of climate change and broader objectives. It examines current understanding of decision making as relevant to climate change.

A-1. Observed Impacts, Vulnerability, and Exposure

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. This conclusion is strengthened by more numerous and improved observations and analyses since the AR4. Evidence of climate-change impacts is strongest and most comprehensive for natural systems. Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences such as changing social and economic factors. In many regions, impacts on natural and human systems are now detected even in the presence of strong confounding factors such as pollution or land use change. See Figure TS.2 and Table TS.1 for a summary of observed impacts, illustrating broader trends presented in this section. Attribution of observed impacts in the WGII AR5 generally links responses of natural and human systems to observed climate change, regardless of its cause. Most reported impacts of climate change are attributed to warming and/or to shifts in precipitation patterns. There is also emerging evidence of impacts of ocean acidification. Relatively few robust attribution studies and meta-analyses have linked impacts in physical and biological systems to anthropogenic climate change. [18.1, 18.3 to 18.6]

Differences in vulnerability and exposure arise from non-climatic factors and from multidimensional inequalities often produced by uneven development processes (*very high confidence*). These differences shape differential risks from climate change. See Figure TS.1 and Box TS.4. Vulnerability and exposure vary over time and across geographic contexts. Changes in poverty or socioeconomic status, ethnic composition, age structure, and governance have had a significant influence on the outcome of past crises associated with climate-related hazards. [8.2, 9.3, 12.2, 13.1, 13.2, 14.1 to 14.3, 19.2, 19.6, 26.8, Box CC-GC]

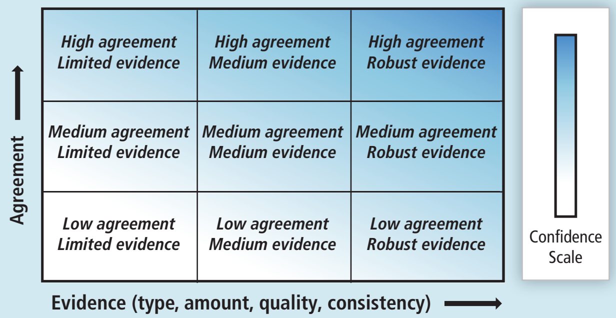
Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (*very high confidence*). Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being. For countries at all levels of development, these impacts are consistent with a significant lack of preparedness for current climate variability in some sectors. The following examples

Box TS.3 | Communication of the Degree of Certainty in Assessment Findings

Based on the Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, the WGII AR5 relies on two metrics for communicating the degree of certainty in key findings:

- Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively.
- Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or both, and expert judgment).

Each finding has its foundation in evaluation of associated evidence and agreement. The summary terms to describe evidence are: *limited*, *medium*, or *robust*; and agreement: *low*, *medium*, or *high*. These terms are presented with some key findings. In many cases, assessment authors in addition evaluate their confidence about the validity of a finding, providing a synthesis of the evaluation of evidence and agreement. Levels of confidence include five qualifiers: *very low*, *low*, *medium*, *high*, and *very high*. Box TS.3 Figure 1 illustrates the flexible relationship between the summary terms for evidence and agreement and the confidence metric. For a given evidence and agreement statement, different confidence levels could be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence.



Box TS.3 Figure 1 | Evidence and agreement statements and their relationship to confidence. The shading increasing toward the top right corner indicates increasing confidence. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence. [Figure 1-3]

When assessment authors evaluate the likelihood, or probability, of some well-defined outcome having occurred or occurring in the future, a finding can include likelihood terms (see below) or a more precise presentation of probability. Use of likelihood is not an alternative to use of confidence. Unless otherwise indicated, findings assigned a likelihood term are associated with *high* or *very high* confidence.

Term	Likelihood of the outcome
Virtually certain	99–100% probability
Extremely likely	95–100% probability
Very likely	90–100% probability
Likely	66–100% probability
More likely than not	>50–100% probability
About as likely as not	33–66% probability
Unlikely	0–33% probability
Very unlikely	0–10% probability
Extremely unlikely	0–5% probability
Exceptionally unlikely	0–1% probability

Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers.

Within paragraphs of this summary, the confidence, evidence, and agreement terms given for a key finding apply to subsequent statements in the paragraph, unless additional terms are provided.

[1.1, Box 1-1]

TS

illustrate impacts of extreme weather and climate events experienced across regional contexts:

- In Africa, extreme weather and climate events including droughts and floods have significant impacts on economic sectors, natural resources, ecosystems, livelihoods, and human health. The floods of the Zambezi River in Mozambique in 2008, for example, displaced 90,000 people, and along the Zambezi River Valley, with approximately 1 million people living in the flood-affected areas, temporary displacement is taking on permanent characteristics. [22.3, 22.4, 22.6]
- Recent floods in Australia and New Zealand caused severe damage to infrastructure and settlements and 35 deaths in Queensland alone (2011). The Victorian heat wave (2009) increased heat-related morbidity and was associated with more than 300 excess deaths, while intense bushfires destroyed more than 2000 buildings and led to 173 deaths. Widespread drought in southeast Australia (1997–2009) and many parts of New Zealand (2007–2009; 2012–2013) resulted in economic losses (e.g., regional GDP in the southern Murray-Darling Basin was below forecast by about 5.7% in 2007–2008, and New Zealand lost about NZ$3.6 billion in direct and off-farm output in 2007–2009). [13.2, 25.6, 25.8, Table 25-1, Boxes 25-5, 25-6, and 25-8]
- In Europe, extreme weather events currently have significant impacts in multiple economic sectors as well as adverse social and health effects (*high confidence*). [Table 23-1]
- In North America, most economic sectors and human systems have been affected by and have responded to extreme weather, including hurricanes, flooding, and intense rainfall (*high confidence*). Extreme heat events currently result in increases in mortality and morbidity (*very high confidence*), with impacts that vary by age, location, and socioeconomic factors (*high confidence*). Extreme coastal storm events have caused excess mortality and morbidity, particularly along the east coast of the United States, and the gulf coast of both Mexico and the United States. Much North American infrastructure is currently vulnerable to extreme weather events (*medium confidence*), with deteriorating water-resource and transportation infrastructure particularly vulnerable (*high confidence*). [26.6, 26.7, Figure 26-2]
- In the Arctic, extreme weather events have had direct and indirect adverse health effects for residents (*high confidence*). [28.2]

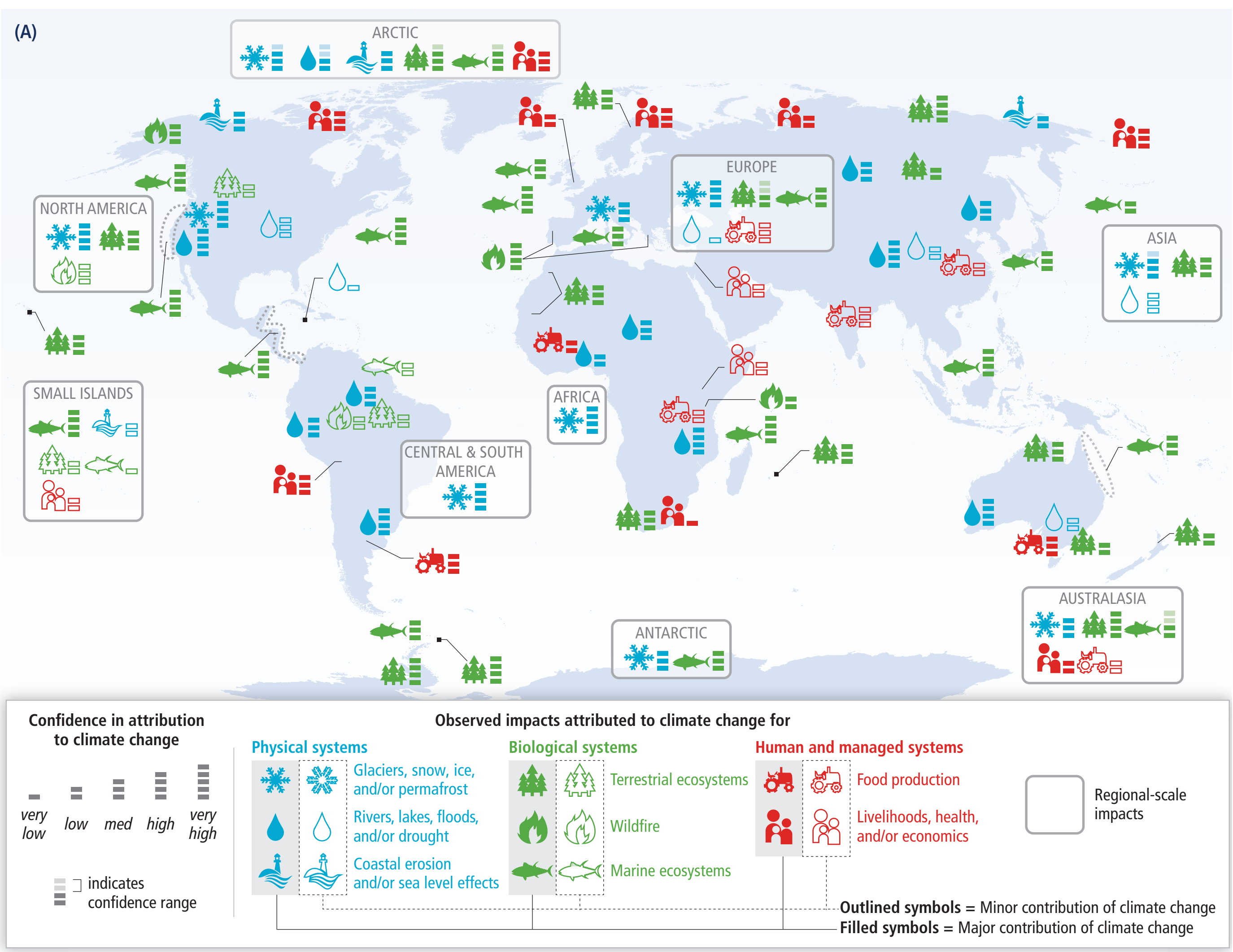


Figure TS.2

Continued next page →

Figure TS.2 (continued)

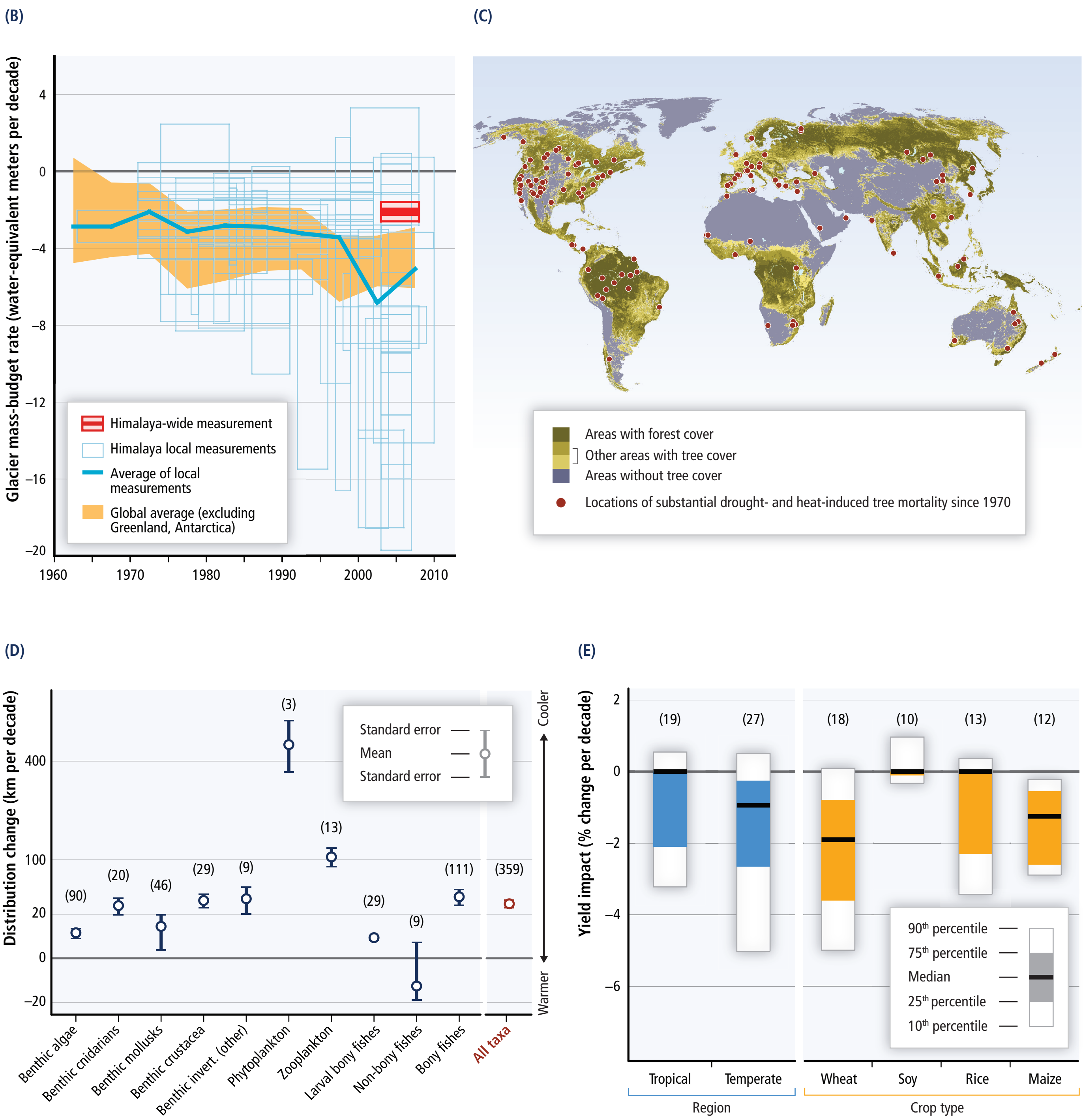


Figure TS.2 | Widespread impacts in a changing world. (A) Global patterns of impacts in recent decades attributed to climate change, based on studies since the AR4. Impacts are shown at a range of geographic scales. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact, and confidence in attribution. See Table TS.1 for descriptions of the impacts. (B) Changes in glacier mass from all published measurements for Himalayan glaciers. Negative values indicate loss of glacier mass. Local measurements are mostly for small, accessible Himalayan glaciers. The blue box for each local Himalaya measurement is centered vertically on its average, and has a height of ±1 standard deviation for annual measurements and a height of ±1 standard error for multiannual measurements. Himalaya-wide measurement (red) was made by satellite laser altimetry. For reference, global average glacier mass change estimates from WGI AR5 4.3 are also shown, with shading indicating ±1 standard deviation. (C) Locations of substantial drought- and heat-induced tree mortality around the globe over 1970–2011. (D) Average rates of change in distribution (km per decade) for marine taxonomic groups based on observations over 1900–2010. Positive distribution changes are consistent with warming (moving into previously cooler waters, generally poleward). The number of responses analyzed is given within parentheses for each category. (E) Summary of estimated impacts of observed climate changes on yields over 1960–2013 for four major crops in temperate and tropical regions, with the number of data points analyzed given within parentheses for each category. [Figures 3-3, 4-7, 7-2, 18-3, and MB-2]

Freshwater Resources

In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (*medium confidence*). Glaciers continue to shrink almost worldwide due to climate change (*high confidence*) (e.g., Figure TS.2B), affecting runoff and water resources downstream (*medium confidence*). Climate change is causing permafrost warming and thawing in high-latitude regions and in high-elevation regions (*high confidence*). There is no evidence that surface water and groundwater drought frequency has changed over the last few decades, although impacts of drought have increased mostly due to increased water demand. [3.2, 4.3, 18.3, 18.5, 24.4, 25.5, 26.2, 28.2, Tables 3-1 and 25-1, Figures 18-2 and 26-1]

Terrestrial and Freshwater Ecosystems

Many terrestrial and freshwater plant and animal species have shifted their geographic ranges and seasonal activities and altered their abundance in response to observed climate change over recent decades, and they are doing so now in many regions (*high confidence*). Increased tree mortality, observed in many places worldwide, has been attributed to climate change in some regions (Figure TS.2C). Increases in the frequency or intensity of ecosystem disturbances such as droughts, wind storms, fires, and pest outbreaks have been detected in many parts of the world and in some cases are attributed to climate change (*medium confidence*). While recent climate change contributed to the extinction of some species of Central American amphibians (*medium confidence*), most recent observed terrestrial

Table TS.1 | Observed impacts attributed to climate change reported in the scientific literature since the AR4. These impacts have been attributed to climate change with *very low*, *low*, *medium*, or *high confidence*, with the relative contribution of climate change to the observed change indicated (major or minor), for natural and human systems across eight major world regions over the past several decades. [Tables 18-5 to 18-9] Absence from the table of additional impacts attributed to climate change does not imply that such impacts have not occurred.

Africa	
Snow & Ice, Rivers & Lakes, Floods & Drought	• Retreat of tropical highland glaciers in East Africa (*high confidence*, major contribution from climate change) • Reduced discharge in West African rivers (*low confidence*, major contribution from climate change) • Lake surface warming and water column stratification increases in the Great Lakes and Lake Kariba (*high confidence*, major contribution from climate change) • Increased soil moisture drought in the Sahel since 1970, partially wetter conditions since 1990 (*medium confidence*, major contribution from climate change) [22.2, 22.3, Tables 18-5, 18-6, and 22-3]
Terrestrial Ecosystems	• Tree density decreases in western Sahel and semi-arid Morocco, beyond changes due to land use (*medium confidence*, major contribution from climate change) • Range shifts of several southern plants and animals, beyond changes due to land use (*medium confidence*, major contribution from climate change) • Increases in wildfires on Mt. Kilimanjaro (*low confidence*, major contribution from climate change) [22.3, Tables 18-7 and 22-3]
Coastal Erosion & Marine Ecosystems	• Decline in coral reefs in tropical African waters, beyond decline due to human impacts (*high confidence*, major contribution from climate change) [Table 18-8]
Food Production & Livelihoods	• Adaptive responses to changing rainfall by South African farmers, beyond changes due to economic conditions (*very low confidence*, major contribution from climate change) • Decline in fruit-bearing trees in Sahel (*low confidence*, major contribution from climate change) • Malaria increases in Kenyan highlands, beyond changes due to vaccination, drug resistance, demography, and livelihoods (*low confidence*, minor contribution from climate change) • Reduced fisheries productivity of Great Lakes and Lake Kariba, beyond changes due to fisheries management and land use (*low confidence*, minor contribution from climate change) [7.2, 11.5, 13.2, 22.3, Table 18-9]
Europe	
Snow & Ice, Rivers & Lakes, Floods & Drought	• Retreat of Alpine, Scandinavian, and Icelandic glaciers (*high confidence*, major contribution from climate change) • Increase in rock slope failures in western Alps (*medium confidence*, major contribution from climate change) • Changed occurrence of extreme river discharges and floods (*very low confidence*, minor contribution from climate change) [18.3, 23.2, 23.3, Tables 18-5 and 18-6; WGI AR5 4.3]
Terrestrial Ecosystems	• Earlier greening, leaf emergence, and fruiting in temperate and boreal trees (*high confidence*, major contribution from climate change) • Increased colonization of alien plant species in Europe, beyond a baseline of some invasion (*medium confidence*, major contribution from climate change) • Earlier arrival of migratory birds in Europe since 1970 (*medium confidence*, major contribution from climate change) • Upward shift in tree-line in Europe, beyond changes due to land use (*low confidence*, major contribution from climate change) • Increasing burnt forest areas during recent decades in Portugal and Greece, beyond some increase due to land use (*high confidence*, major contribution from climate change) [4.3, 18.3, Tables 18-7 and 23-6]
Coastal Erosion & Marine Ecosystems	• Northward distributional shifts of zooplankton, fishes, seabirds, and benthic invertebrates in northeast Atlantic (*high confidence*, major contribution from climate change) • Northward and depth shift in distribution of many fish species across European seas (*medium confidence*, major contribution from climate change) • Plankton phenology changes in northeast Atlantic (*medium confidence*, major contribution from climate change) • Spread of warm water species into the Mediterranean, beyond changes due to invasive species and human impacts (*medium confidence*, major contribution from climate change) [6.3, 23.6, 30.5, Tables 6-2 and 18-8, Boxes 6-1 and CC-MB]
Food Production & Livelihoods	• Shift from cold-related mortality to heat-related mortality in England and Wales, beyond changes due to exposure and health care (*low confidence*, major contribution from climate change) • Impacts on livelihoods of Sámi people in northern Europe, beyond effects of economic and sociopolitical changes (*medium confidence*, major contribution from climate change) • Stagnation of wheat yields in some countries in recent decades, despite improved technology (*medium confidence*, minor contribution from climate change) • Positive yield impacts for some crops mainly in northern Europe, beyond increase due to improved technology (*medium confidence*, minor contribution from climate change) • Spread of bluetongue virus in sheep and of ticks across parts of Europe (*medium confidence*, minor contribution from climate change) [18.4, 23.4, 23.5, Table 18-9, Figure 7-2]

Continued next page →

Table TS.1 (continued)

Asia	
Snow & Ice, Rivers & Lakes, Floods & Drought	• Permafrost degradation in Siberia, Central Asia, and Tibetan Plateau (*high confidence*, major contribution from climate change) • Shrinking mountain glaciers across most of Asia (*medium confidence*, major contribution from climate change) • Changed water availability in many Chinese rivers, beyond changes due to land use (*low confidence*, minor contribution from climate change) • Increased flow in several rivers due to shrinking glaciers (*high confidence*, major contribution from climate change) • Earlier timing of maximum spring flood in Russian rivers (*medium confidence*, major contribution from climate change) • Reduced soil moisture in north-central and northeast China (1950–2006) (*medium confidence*, major contribution from climate change) • Surface water degradation in parts of Asia, beyond changes due to land use (*medium confidence*, minor contribution from climate change) [24.3, 24.4, 28.2, Tables 18-5, 18-6, and SM24-4, Box 3-1; WGI AR5 4.3, 10.5]
Terrestrial Ecosystems	• Changes in plant phenology and growth in many parts of Asia (earlier greening), particularly in the north and east (*medium confidence*, major contribution from climate change) • Distribution shifts of many plant and animal species upwards in elevation or polewards, particularly in the north of Asia (*medium confidence*, major contribution from climate change) • Invasion of Siberian larch forests by pine and spruce during recent decades (*low confidence*, major contribution from climate change) • Advance of shrubs into the Siberian tundra (*high confidence*, major contribution from climate change) [4.3, 24.4, 28.2, Table 18-7, Figure 4-4]
Coastal Erosion & Marine Ecosystems	• Decline in coral reefs in tropical Asian waters, beyond decline due to human impacts (*high confidence*, major contribution from climate change) • Northward range extension of corals in the East China Sea and western Pacific, and of a predatory fish in the Sea of Japan (*medium confidence*, major contribution from climate change) • Shift from sardines to anchovies in the western North Pacific, beyond fluctuations due to fisheries (*low confidence*, major contribution from climate change) • Increased coastal erosion in Arctic Asia (*low confidence*, major contribution from climate change) [6.3, 24.4, 30.5, Tables 6-2 and 18-8]
Food Production & Livelihoods	• Impacts on livelihoods of indigenous groups in Arctic Russia, beyond economic and sociopolitical changes (*low confidence*, major contribution from climate change) • Negative impacts on aggregate wheat yields in South Asia, beyond increase due to improved technology (*medium confidence*, minor contribution from climate change) • Negative impacts on aggregate wheat and maize yields in China, beyond increase due to improved technology (*low confidence*, minor contribution from climate change) • Increases in a water-borne disease in Israel (*low confidence*, minor contribution from climate change) [7.2, 13.2, 18.4, 28.2, Tables 18-4 and 18-9, Figure 7-2]
Australasia	
Snow & Ice, Rivers & Lakes, Floods & Drought	• Significant decline in late-season snow depth at 3 of 4 alpine sites in Australia (1957–2002) (*medium confidence*, major contribution from climate change) • Substantial reduction in ice and glacier ice volume in New Zealand (*medium confidence*, major contribution from climate change) • Intensification of hydrological drought due to regional warming in southeast Australia (*low confidence*, minor contribution from climate change) • Reduced inflow in river systems in southwestern Australia (since the mid-1970s) (*high confidence*, major contribution from climate change) [25.5, Tables 18-5, 18-6, and 25-1; WGI AR5 4.3]
Terrestrial Ecosystems	• Changes in genetics, growth, distribution, and phenology of many species, in particular birds, butterflies, and plants in Australia, beyond fluctuations due to variable local climates, land use, pollution, and invasive species (*high confidence*, major contribution from climate change) • Expansion of some wetlands and contraction of adjacent woodlands in southeast Australia (*low confidence*, major contribution from climate change) • Expansion of monsoon rainforest at expense of savannah and grasslands in northern Australia (*medium confidence*, major contribution from climate change) • Migration of glass eels advanced by several weeks in Waikato River, New Zealand (*low confidence*, major contribution from climate change) [Tables 18-7 and 25-3]
Coastal Erosion & Marine Ecosystems	• Southward shifts in the distribution of marine species near Australia, beyond changes due to short-term environmental fluctuations, fishing, and pollution (*medium confidence*, major contribution from climate change) • Change in timing of migration of seabirds in Australia (*low confidence*, major contribution from climate change) • Increased coral bleaching in Great Barrier Reef and western Australian reefs, beyond effects from pollution and physical disturbance (*high confidence*, major contribution from climate change) • Changed coral disease patterns at Great Barrier Reef, beyond effects from pollution (*medium confidence*, major contribution from climate change) [6.3, 25.6, Tables 18-8 and 25-3]
Food Production & Livelihoods	• Advanced timing of wine-grape maturation in recent decades, beyond advance due to improved management (*medium confidence*, major contribution from climate change) • Shift in winter vs. summer human mortality in Australia, beyond changes due to exposure and health care (*low confidence*, major contribution from climate change) • Relocation or diversification of agricultural activities in Australia, beyond changes due to policy, markets, and short-term climate variability (*low confidence*, minor contribution from climate change) [11.4, 18.4, 25.7, 25.8, Tables 18-9 and 25-3, Box 25-5]
North America	
Snow & Ice, Rivers & Lakes, Floods & Drought	• Shrinkage of glaciers across western and northern North America (*high confidence*, major contribution from climate change) • Decreasing amount of water in spring snowpack in western North America (1960–2002) (*high confidence*, major contribution from climate change) • Shift to earlier peak flow in snow dominated rivers in western North America (*high confidence*, major contribution from climate change) • Increased runoff in the midwestern and northeastern US (*medium confidence*, minor contribution from climate change) [Tables 18-5 and 18-6; WGI AR5 2.6, 4.3]
Terrestrial Ecosystems	• Phenology changes and species distribution shifts upward in elevation and northward across multiple taxa (*medium confidence*, major contribution from climate change) • Increased wildfire frequency in subarctic conifer forests and tundra (*medium confidence*, major contribution from climate change) • Regional increases in tree mortality and insect infestations in forests (*low confidence*, minor contribution from climate change) • Increase in wildfire activity, fire frequency and duration, and burnt area in forests of the western US and boreal forests in Canada, beyond changes due to land use and fire management (*medium confidence*, minor contribution from climate change) [26.4, 28.2, Table 18-7, Box 26-2]
Coastal Erosion & Marine Ecosystems	• Northward distributional shifts of northwest Atlantic fish species (*high confidence*, major contribution from climate change) • Changes in musselbeds along the west coast of US (*high confidence*, major contribution from climate change) • Changed migration and survival of salmon in northeast Pacific (*high confidence*, major contribution from climate change) • Increased coastal erosion in Alaska and Canada (*medium confidence*, major contribution from climate change) [18.3, 30.5, Tables 6-2 and 18-8]
Food Production & Livelihoods	• Impacts on livelihoods of indigenous groups in the Canadian Arctic, beyond effects of economic and sociopolitical changes (*medium confidence*, major contribution from climate change) [18.4, 28.2, Tables 18-4 and 18-9]

Continued next page →

Table TS.1 (continued)

Central and South America	
Snow & Ice, Rivers & Lakes, Floods & Drought	• Shrinkage of Andean glaciers (*high confidence*, major contribution from climate change) • Changes in extreme flows in Amazon River (*medium confidence*, major contribution from climate change) • Changing discharge patterns in rivers in the western Andes (*medium confidence*, major contribution from climate change) • Increased streamflow in sub-basins of the La Plata River, beyond increase due to land-use change (*high confidence*, major contribution from climate change) [27.3, Tables 18-5, 18-6, and 27-3; WGI AR5 4.3]
Terrestrial Ecosystems	• Increased tree mortality and forest fire in the Amazon (*low confidence*, minor contribution from climate change) • Rainforest degradation and recession in the Amazon, beyond reference trends in deforestation and land degradation (*low confidence*, minor contribution from climate change) [4.3, 18.3, 27.2, 27.3, Table 18-7]
Coastal Erosion & Marine Ecosystems	• Increased coral bleaching in western Caribbean, beyond effects from pollution and physical disturbance (*high confidence*, major contribution from climate change) • Mangrove degradation on north coast of South America, beyond degradation due to pollution and land use (*low confidence*, minor contribution from climate change) [27.3, Table 18-8]
Food Production & Livelihoods	• More vulnerable livelihood trajectories for indigenous Aymara farmers in Bolivia due to water shortage, beyond effects of increasing social and economic stress (*medium confidence*, major contribution from climate change) • Increase in agricultural yields and expansion of agricultural areas in southeastern South America, beyond increase due to improved technology (*medium confidence*, major contribution from climate change) [13.1, 27.3, Table 18-9]
Polar Regions	
Snow & Ice, Rivers & Lakes, Floods & Drought	• Decreasing Arctic sea ice cover in summer (*high confidence*, major contribution from climate change) • Reduction in ice volume in Arctic glaciers (*high confidence*, major contribution from climate change) • Decreasing snow cover extent across the Arctic (*medium confidence*, major contribution from climate change) • Widespread permafrost degradation, especially in the southern Arctic (*high confidence*, major contribution from climate change) • Ice mass loss along coastal Antarctica (*medium confidence*, major contribution from climate change) • Increased river discharge for large circumpolar rivers (1997–2007) (*low confidence*, major contribution from climate change) • Increased winter minimum river flow in most of the Arctic (*medium confidence*, major contribution from climate change) • Increased lake water temperatures 1985–2009 and prolonged ice-free seasons (*medium confidence*, major contribution from climate change) • Disappearance of thermokarst lakes due to permafrost degradation in the low Arctic. New lakes created in areas of formerly frozen peat (*high confidence*, major contribution from climate change) [28.2, Tables 18-5 and 18-6; WGI AR5 4.2 to 4.4, 4.6, 10.5]
Terrestrial Ecosystems	• Increased shrub cover in tundra in North America and Eurasia (*high confidence*, major contribution from climate change) • Advance of Arctic tree-line in latitude and altitude (*medium confidence*, major contribution from climate change) • Changed breeding area and population size of subarctic birds, due to snowbed reduction and/or tundra shrub encroachment (*medium confidence*, major contribution from climate change) • Loss of snow-bed ecosystems and tussock tundra (*high confidence*, major contribution from climate change) • Impacts on tundra animals from increased ice layers in snow pack, following rain-on-snow events (*medium confidence*, major contribution from climate change) • Increased plant species ranges in the West Antarctic Peninsula and nearby islands over the past 50 years (*high confidence*, major contribution from climate change) • Increased phytoplankton productivity in Signy Island lake waters (*high confidence*, major contribution from climate change) [28.2, Table 18-7]
Coastal Erosion & Marine Ecosystems	• Increased coastal erosion across Arctic (*medium confidence*, major contribution from climate change) • Negative effects on non-migratory Arctic species (*high confidence*, major contribution from climate change) • Decreased reproductive success in Arctic seabirds (*medium confidence*, major contribution from climate change) • Decline in Southern Ocean seals and seabirds (*medium confidence*, major contribution from climate change) • Reduced thickness of foraminiferal shells in southern oceans, due to ocean acidification (*medium confidence*, major contribution from climate change) • Reduced krill density in Scotia Sea (*medium confidence*, major contribution from climate change) [6.3, 18.3, 28.2, 28.3, Table 18-8]
Food Production & Livelihoods	• Impact on livelihoods of Arctic indigenous peoples, beyond effects of economic and sociopolitical changes (*medium confidence*, major contribution from climate change) • Increased shipping traffic across the Bering Strait (*medium confidence*, major contribution from climate change) [18.4, 28.2, Tables 18-4 and 18-9, Figure 28-4]
Small Islands	
Snow & Ice, Rivers & Lakes, Floods & Drought	• Increased water scarcity in Jamaica, beyond increase due to water use (*very low confidence*, minor contribution from climate change) [Table 18-6]
Terrestrial Ecosystems	• Tropical bird population changes in Mauritius (*medium confidence*, major contribution from climate change) • Decline of an endemic plant in Hawai'i (*medium confidence*, major contribution from climate change) • Upward trend in tree-lines and associated fauna on high-elevation islands (*low confidence*, minor contribution from climate change) [29.3, Table 18-7]
Coastal Erosion & Marine Ecosystems	• Increased coral bleaching near many tropical small islands, beyond effects of degradation due to fishing and pollution (*high confidence*, major contribution from climate change) • Degradation of mangroves, wetlands, and seagrass around small islands, beyond degradation due to other disturbances (*very low confidence*, minor contribution from climate change) • Increased flooding and erosion, beyond erosion due to human activities, natural erosion, and accretion (*low confidence*, minor contribution from climate change) • Degradation of groundwater and freshwater ecosystems due to saline intrusion, beyond degradation due to pollution and groundwater pumping (*low confidence*, minor contribution from climate change) [29.3, Table 18-8]
Food Production & Livelihoods	• Increased degradation of coastal fisheries due to direct effects and effects of increased coral reef bleaching, beyond degradation due to overfishing and pollution (*low confidence*, minor contribution from climate change) [18.3, 18.4, 29.3, 30.6, Table 18-9, Box CC-CR]

TS

species extinctions have not been attributed to climate change (*high confidence*). [4.2, 4.4, 18.3, 18.5, 22.3, 25.6, 26.4, 28.2, Figure 4-10, Boxes 4-2, 4-3, 4-4, and 25-3]

Coastal Systems and Low-lying Areas

Coastal systems are particularly sensitive to changes in sea level and ocean temperature and to ocean acidification (*very high confidence*). Coral bleaching and species range shifts have been attributed to changes in ocean temperature. For many other coastal changes, the impacts of climate change are difficult to identify given other human-related drivers (e.g. land use change, coastal development, pollution) (*robust evidence*, *high agreement*). [5.3 to 5.5, 18.3, 25.6, 26.4, Box 25-3]

Marine Systems

Warming has caused and will continue to cause shifts in the abundance, geographic distribution, migration patterns, and timing of seasonal activities of marine species (*very high confidence*), paralleled by reduction in maximum body sizes (*medium confidence*). This has resulted and will further result in changing interactions between species, including competition and predator-prey dynamics (*high confidence*). Numerous observations over the last decades in all ocean basins show global-scale changes including large-scale distribution shifts of species (*very high confidence*) and altered ecosystem composition (*high confidence*) on multi-decadal time scales, tracking climate trends. Many fishes, invertebrates, and phytoplankton have shifted their distribution and/or abundance poleward and/or to deeper, cooler waters (Figure TS.2D). Some warm-water corals and their reefs have responded to warming with species replacement, bleaching, and decreased coral cover causing habitat loss. Few field observations to date demonstrate biological responses attributable to anthropogenic ocean acidification, as in many places these responses are not yet outside their natural variability and may be influenced by confounding local or regional factors. See also Box TS.7. Natural global climate change at rates slower than current anthropogenic climate change caused significant ecosystem shifts, including species emergences and extinctions, during the past millions of years. [5.4, 6.1, 6.3 to 6.5, 18.3, 18.5, 22.3, 25.6, 26.4, 30.4, 30.5, Boxes 25-3, CC-OA, CC-CR, and CC-MB]

Vulnerability of most marine organisms to warming is set by their physiology, which defines their limited temperature ranges and hence their thermal sensitivity (*high confidence*). See Figure TS.3. Temperature defines the geographic distribution of many species and their responses to climate change. Shifting temperature means and extremes alter habitat (e.g., sea ice and coastal habitat), and cause changes in species abundances through local extinctions and latitudinal distribution expansions or shifts of up to hundreds of kilometers per decade (*very high confidence*). Although genetic adaptation occurs (*medium confidence*), the capacity of fauna and flora to compensate for or keep up with the rate of ongoing thermal change is limited (*low confidence*). [6.3, 6.5, 30.5]

Oxygen minimum zones are progressively expanding in the tropical Pacific, Atlantic, and Indian Oceans, due to reduced ventilation and O_2 solubilities in more stratified oceans at higher temperatures (*high confidence*). In combination with human activities that increase the productivity of coastal systems, hypoxic areas ("dead zones") are increasing in number and size. Regional exacerbation of hypoxia causes shifts to hypoxia-tolerant biota and reduces habitat for commercially relevant species, with implications for fisheries. [6.1, 6.3, 30.3, 30.5, 30.6; WGI AR5 3.8]

Food Security and Food Production Systems

Based on many studies covering a wide range of regions and crops, negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*). The smaller number of studies showing positive impacts relate mainly to high-latitude regions, though it is not yet clear whether the balance of impacts has been negative or positive in these regions. Climate change has negatively affected wheat and maize yields for many regions and in the global aggregate (*medium confidence*). Effects on rice and soybean yield have been smaller in major production regions and globally, with a median change of zero across all available data, which are fewer for soy compared to the other crops. Observed impacts relate mainly to production aspects of food security rather than access or other components of food security. See Figure TS.2E. Since AR4, several periods of rapid food and cereal price increases following climate extremes in key producing regions indicate a sensitivity of current markets to climate extremes among other factors (*medium confidence*). Crop yields have a large negative sensitivity to extreme daytime temperatures around 30°C, throughout the growing season (*high confidence*). CO_2 has stimulatory effects on crop yields in most cases, and elevated tropospheric ozone has damaging effects. Interactions among CO_2 and ozone, mean temperature, extremes, water, and nitrogen are non-linear and difficult to predict (*medium confidence*). [7.2, 7.3, 18.4, 22.3, 26.5, Figures 7-2, 7-3, and 7-7, Box 25-3]

Urban Areas

Urban areas hold more than half the world's population and most of its built assets and economic activities. A high proportion of the population and economic activities at risk from climate change are in urban areas, and a high proportion of global greenhouse gas emissions are generated by urban-based activities and residents. Cities are composed of complex inter-dependent systems that can be leveraged to support climate change adaptation via effective city governments supported by cooperative multilevel governance (*medium confidence*). This can enable synergies with infrastructure investment and maintenance, land use management, livelihood creation, and ecosystem services protection. [8.1, 8.3, 8.4]

Rapid urbanization and growth of large cities in developing countries have been accompanied by expansion of highly vulnerable urban communities living in informal settlements, many of which are on land exposed to extreme weather (*medium confidence*). [8.2, 8.3]

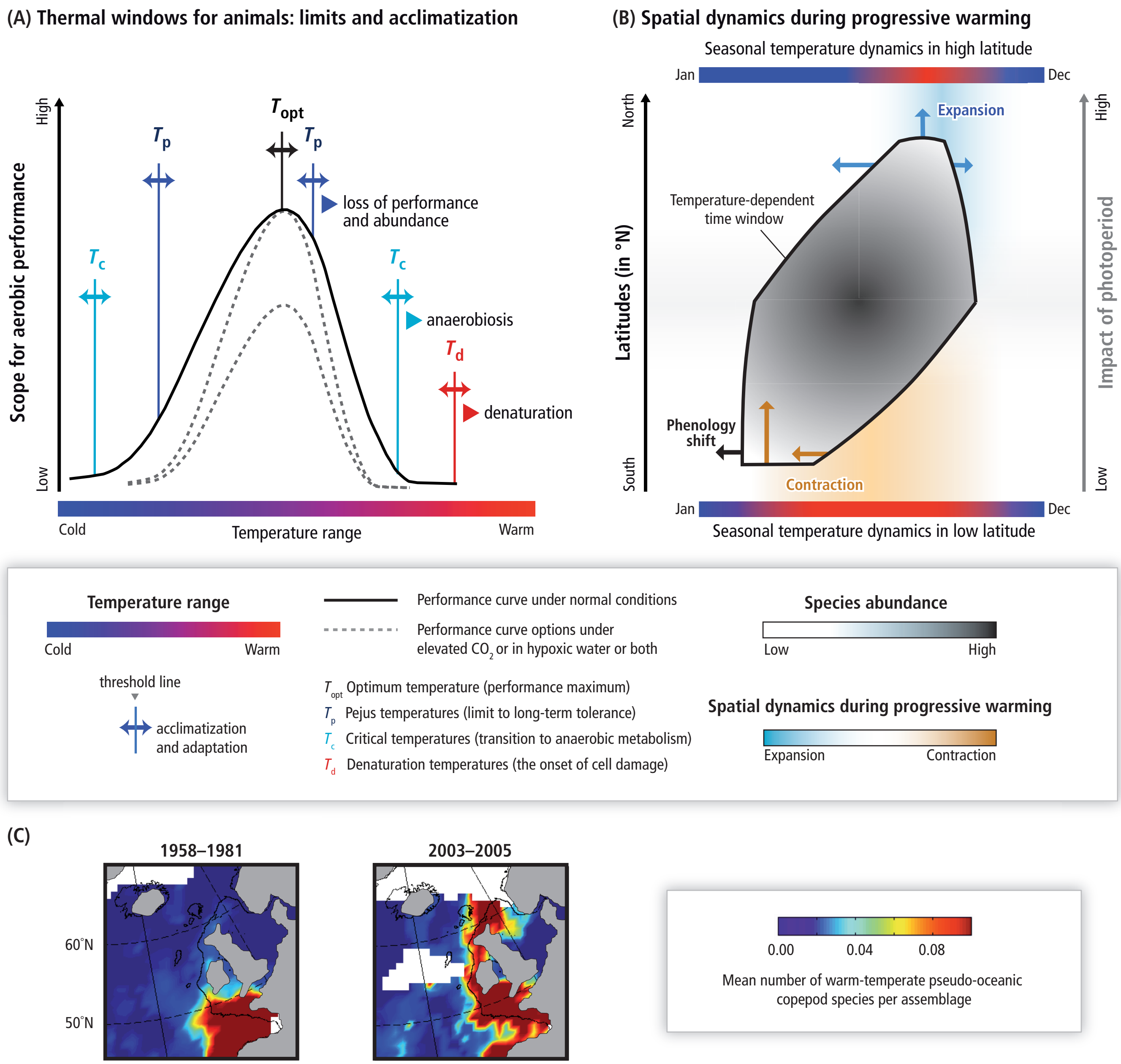


Figure TS.3 | Temperature specialization of species (A), which is influenced by other factors such as oxygen, causes warming-induced distribution shifts (B), for example, the northward expansion of warm-temperate species in the northeast Atlantic (C). These distribution changes depend on species-specific physiology and ecology. Detailed introduction of each panel follows: (A) The temperature tolerance range and performance levels of an organism are described by its performance curve. Each performance (e.g., exercise, growth, reproduction) is highest at optimum temperature (T_{opt}) and lower at cooler or warmer temperatures. Surpassing temperature thresholds (T_p) means going into time-limited tolerance, and more extreme temperature changes lead to exceedance of thresholds that cause metabolic disturbances (T_c) and ultimately onset of cell damage (T_d). These thresholds for an individual can shift (horizontal arrows), within limits, between summer and winter (seasonal acclimatization) or when the species adapts to a cooler or warmer climate over generations (evolutionary adaptation). Under elevated CO_2 levels (ocean acidification) or low oxygen, thermal windows narrow (dashed gray curves). (B) During climate warming, a species follows its normal temperatures as it moves or is displaced, typically resulting in a poleward shift of the biogeographic range (exemplified for the Northern Hemisphere). The polygon delineates the distribution range in space and seasonal time; the level of gray denotes abundance. (C) Long-term changes in the mean number of warm-temperate pseudo-oceanic copepod species in the northeast Atlantic from 1958 to 2005. [Figures 6-5, 6-7, and 6-8]

Rural Areas

Climate change in rural areas will take place in the context of many important economic, social, and land use trends (*very high confidence*). In different regions, absolute rural populations have peaked or will peak in the next few decades. The proportion of the rural population depending on agriculture is varied across regions, but declining everywhere. Poverty rates in rural areas are higher than overall poverty rates, but also falling more sharply, and the proportions of population in extreme poverty accounted for by rural people are also falling: in both cases with the exception of sub-Saharan Africa, where these rates are rising. Accelerating globalization, through migration, labor linkages, regional and international trade, and new information and communication technologies, is bringing about economic transformation in rural areas of developing and developed countries. [9.3, Figure 9-2]

For rural households and communities, access to land and natural resources, flexible local institutions, knowledge and information, and livelihood strategies can contribute to resilience to climate change (*high confidence*). Especially in developing countries, rural people are subject to multiple non-climatic stressors, including underinvestment in agriculture, problems with land and natural resource policy, and processes of environmental degradation (*very high confidence*). In developed countries, there are important shifts toward multiple uses of rural areas, especially leisure uses, and new rural policies based on the collaboration of multiple stakeholders, the targeting of multiple sectors, and a change from subsidy-based to investment-based policy. [9.3, 22.4, Table 9-3]

Key Economic Sectors and Services

Economic losses due to extreme weather events have increased globally, mostly due to increase in wealth and exposure, with a possible influence of climate change (*low confidence* in attribution to climate change). Flooding can have major economic costs, both in term of impacts (e.g., capital destruction, disruption) and adaptation (e.g., construction, defensive investment) (*robust evidence*, *high agreement*). Since the mid-20th century, socioeconomic losses from flooding have increased mainly due to greater exposure and vulnerability (*high confidence*). [3.2, 3.4, 10.3, 18.4, 23.2, 23.3, 26.7, Figure 26-2, Box 25-7]

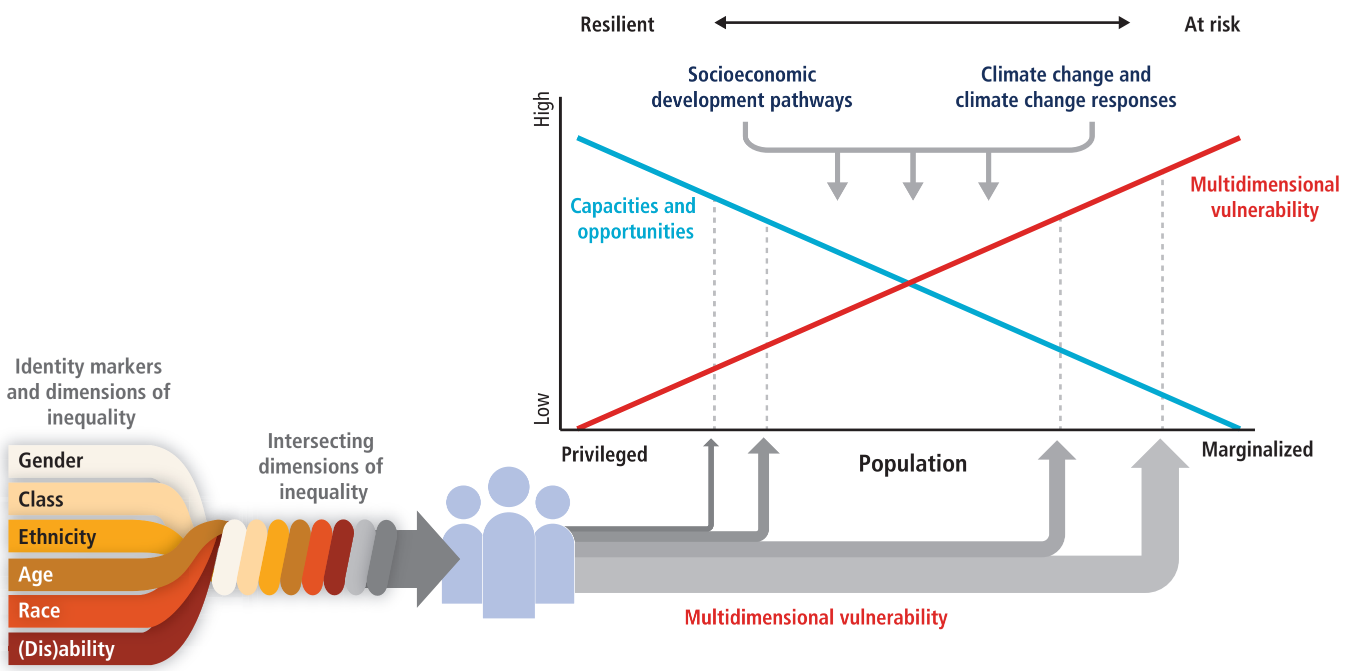
Human Health

At present the worldwide burden of human ill-health from climate change is relatively small compared with effects of other stressors and is not well quantified. However, there has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming (*medium confidence*). Local changes in temperature and rainfall have altered the distribution of some waterborne illnesses and disease vectors (*medium confidence*). [11.4 to 11.6, 18.4, 25.8]

The health of human populations is sensitive to shifts in weather patterns and other aspects of climate change (*very high confidence*). These effects occur directly, due to changes in temperature and precipitation and in the occurrence of heat waves, floods, droughts, and fires. Health may be damaged indirectly by climate change-related ecological disruptions, such as crop failures or shifting patterns of disease vectors, or by social responses to climate change, such as displacement of populations following prolonged drought. Variability in temperatures is a risk factor in its own right, over and above the influence of average temperatures on heat-related deaths. [11.4, 28.2]

Human Security

Challenges for vulnerability reduction and adaptation actions are particularly high in regions that have shown severe difficulties in governance (*high confidence*). Violent conflict increases vulnerability to climate change (*medium evidence*, *high agreement*). Large-scale violent conflict harms assets that facilitate adaptation, including infrastructure, institutions, natural resources, social capital, and livelihood opportunities. [12.5, 19.2, 19.6]



Box TS.4 Figure 1 | Multidimensional vulnerability driven by intersecting dimensions of inequality. Vulnerability increases when people's capacities and opportunities to adapt to climate change and adjust to climate change responses are diminished. [Figure 13-5]

Box TS.4 | Multidimensional Inequality and Vulnerability to Climate Change

People who are socially, economically, culturally, politically, institutionally, or otherwise marginalized in society are especially vulnerable to climate change and also to some adaptation and mitigation responses (*medium evidence*, *high agreement*). This heightened vulnerability is rarely due to a single cause. Rather, it is the product of intersecting social processes that result in inequalities in socioeconomic status and income, as well as in exposure. Such social processes include, for example, discrimination on the basis of gender, class, race/ethnicity, age, and (dis)ability. See Box TS.4 Figure 1 on previous page. Understanding differential capacities and opportunities of individuals, households, and communities requires knowledge of these intersecting social drivers, which may be context-specific and clustered in diverse ways (e.g., class and ethnicity in one case, gender and age in another). Few studies depict the full spectrum of these intersecting social processes and the ways in which they shape multidimensional vulnerability to climate change.

Examples of inequality-driven impacts and risks of climate change and climate change responses (*medium evidence*, *high agreement*):

- Privileged members of society can benefit from climate change impacts and response strategies, given their flexibility in mobilizing and accessing resources and positions of power, often to the detriment of others. [13.2, 13.3, 22.4, 26.8]
- Differential impacts on men and women arise from distinct roles in society, the way these roles are enhanced or constrained by other dimensions of inequality, risk perceptions, and the nature of response to hazards. [8.2, 9.3, 11.3, 12.2, 13.2, 18.4, 19.6, 22.4, Box CC-GC]
- Both male and female deaths are recorded after flooding, affected by socioeconomic disadvantage, occupation, and culturally imposed expectations to save lives. Although women are generally more sensitive to heat stress, more male workers are reported to have died largely as a result of responsibilities related to outdoor and indoor work. [11.3, 13.2, Box CC-GC]
- Women often experience additional duties as laborers and caregivers as a result of extreme weather events and climate change, as well as responses (e.g., male outmigration), while facing more psychological and emotional distress, reduced food intake, adverse mental health outcomes due to displacement, and in some cases increasing incidences of domestic violence. [9.3, 9.4, 12.4, 13.2, Box CC-GC]
- Children and the elderly are often at higher risk due to narrow mobility, susceptibility to infectious diseases, reduced caloric intake, and social isolation. While adults and older children are more severely affected by some climate-sensitive vector-borne diseases such as dengue, young children are more likely to die from or be severely compromised by diarrheal diseases and floods. The elderly face disproportional physical harm and death from heat stress, droughts, and wildfires. [8.2, 10.9, 11.1, 11.4, 11.5, 13.2, 22.4, 23.5, 26.6]
- In most urban areas, low-income groups, including migrants, face large climate change risks because of poor-quality, insecure, and clustered housing, inadequate infrastructure, and lack of provision for health care, emergency services, flood exposure, and measures for disaster risk reduction. [8.1, 8.2, 8.4, 8.5, 12.4, 22.3, 26.8]
- People disadvantaged by race or ethnicity, especially in developed countries, experience more harm from heat stress, often due to low economic status and poor health conditions, and displacement after extreme events. [11.3, 12.4, 13.2]
- Livelihoods and lifestyles of indigenous peoples, pastoralists, and fisherfolk, often dependent on natural resources, are highly sensitive to climate change and climate change policies, especially those that marginalize their knowledge, values, and activities. [9.3, 11.3, 12.3, 14.2, 22.4, 25.8, 26.8, 28.2]
- Disadvantaged groups without access to land and labor, including female-headed households, tend to benefit less from climate change response mechanisms (e.g., Clean Development Mechanism (CDM), Reduction of Emissions from Deforestation and Forest Degradation (REDD+), large-scale land acquisition for biofuels, and planned agricultural adaptation projects). [9.3, 12.2, 12.5, 13.3, 22.4, 22.6]

Livelihoods and Poverty

Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty (*high confidence*). Climate-related hazards affect poor people's lives directly through impacts on livelihoods, reductions in crop yields, or destruction of homes and indirectly through, for example, increased food prices and food insecurity. Urban and rural transient poor who face multiple deprivations can slide into chronic poverty as a result of extreme events, or a series of events, when unable to rebuild their eroded assets (*limited evidence*, *high agreement*). Observed positive effects for poor and marginalized people, which are limited and often indirect, include examples such as diversification of social networks and of agricultural practices. [8.2, 8.3, 9.3, 11.3, 13.1 to 13.3, 22.3, 24.4, 26.8]

Livelihoods of indigenous peoples in the Arctic have been altered by climate change, through impacts on food security and traditional and cultural values (*medium confidence*). There is emerging evidence of climate change impacts on livelihoods of indigenous people in other regions. [18.4, Table 18-9, Box 18-5]

A-2. Adaptation Experience

Throughout history, people and societies have adjusted to and coped with climate, climate variability, and extremes, with varying degrees of success. This section focuses on adaptive human responses to observed and projected climate-change impacts, which can also address broader risk-reduction and development objectives.

Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). Engineered and technological options are commonly implemented adaptive responses, often integrated within existing programs such as disaster risk management and water management. There is increasing recognition of the value of social, institutional, and ecosystem-based measures and of the extent of constraints to adaptation. Adaptation options adopted to date continue to emphasize incremental adjustments and co-benefits and are starting to emphasize flexibility and learning (*medium evidence*, *medium agreement*). [4.4, 5.5, 6.4, 8.3, 9.4, 11.7, 14.1, 14.3, 15.2 to 15.5, 17.2, 17.3, 22.4, 23.7, 25.4, 25.10, 26.8, 26.9, 27.3, 30.6, Boxes 25-1, 25-2, 25-9, and CC-EA]

Most assessments of adaptation have been restricted to impacts, vulnerability, and adaptation planning, with very few assessing the processes of implementation or the effects of adaptation actions (*medium evidence*, *high agreement*). Vulnerability indicators define, quantify, and weight aspects of vulnerability across regional units, but methods of constructing indices are subjective, often lack transparency, and can be difficult to interpret. There are conflicting views on the choice of adaptation metrics, given differing values placed on needs and outcomes, many of which cannot be captured in a comparable way by metrics. Indicators proving most useful for policy learning are those that track not just process and implementation, but also the extent to which targeted outcomes are occurring. Multi-metric evaluations including risk and uncertainty are increasingly used, an evolution from a previous focus on cost-benefit analysis and identification of "best economic adaptations" (*high confidence*). Adaptation assessments best suited to delivering effective adaptation measures often include both top-down assessments of biophysical climate changes and bottom-up assessments of vulnerability targeted toward local solutions to globally derived risks and toward particular decisions. [4.4, 14.4, 14.5, 15.2, 15.3, 17.2, 17.3, 21.3, 21.5, 22.4, 25.4, 25.10, 26.8, 26.9, Box CC-EA]

Adaptation experience is accumulating across regions in the public and private sector and within communities (*high confidence*). Governments at various levels are starting to develop adaptation plans and policies and to integrate climate-change considerations into broader development plans. Examples of adaptation across regions and contexts include the following:

- Urban adaptation has emphasized city-based disaster risk management such as early warning systems and infrastructure investments; ecosystem-based adaptation and green roofs; enhanced storm and wastewater management; urban and peri-urban agriculture improving food security; enhanced social protection; and good-quality, affordable, and well-located housing (*high confidence*). [8.3, 8.4, 15.4, 26.8, Boxes 25-9, CC-UR, and CC-EA]
- There is a growing body of literature on adaptation practices in both developed and developing country rural areas, including documentation of practical experience in agriculture, water, forestry, and biodiversity and, to a lesser extent, fisheries (*very high confidence*). Public policies supporting decision making for adaptation in rural areas exist in developed and, increasingly, developing countries, and there are also examples of private adaptations led by individuals, companies, and nongovernmental organizations (NGOs) (*high confidence*). Adaptation constraints, particularly pronounced in developing countries, result from lack of access to credit, land, water, technology, markets, information, and perceptions of the need to change. [9.4, 17.3, Tables 9-7 and 9-8]
- In Africa, most national governments are initiating governance systems for adaptation (*high confidence*). Progress on national and subnational policies and strategies has initiated the mainstreaming of adaptation into sectoral planning, but evolving institutional frameworks cannot yet effectively coordinate the range of adaptation initiatives being implemented. Disaster risk management, adjustments in technologies and infrastructure, ecosystem-based approaches, basic public health measures, and livelihood diversification are reducing vulnerability, although efforts to date tend to be isolated. [22.4]
- In Europe, adaptation policy has been developed at international (EU), national, and local government levels, with limited systematic information on current implementation or effectiveness (*high confidence*). Some adaptation planning has been integrated into coastal and water management, into environmental protection and land planning, and into disaster risk management. [23.7, Boxes 5-1 and 23-3]
- In Asia, adaptation is being facilitated in some areas through mainstreaming climate adaptation action into subnational development planning, early warning systems, integrated water resources management, agroforestry, and coastal reforestation of mangroves (*high confidence*). [24.4 to 24.6, 24.9, Box CC-TC]
- In Australasia, planning for sea level rise, and in southern Australia for reduced water availability, is becoming adopted widely. Planning

TS

Table TS.2 | Illustrative examples of adaptation experience, as well as approaches to reducing vulnerability and enhancing resilience. Adaptation actions can be influenced by climate variability, extremes, and change, and by exposure and vulnerability at the scale of risk management. Many examples and case studies demonstrate complexity at the level of communities or specific regions within a country. It is at this spatial scale that complex interactions between vulnerability, exposure, and climate change come to the fore. [Table 21-4]

Early warning systems for heat	
Exposure and vulnerability	Factors affecting exposure and vulnerability include age, preexisting health status, level of outdoor activity, socioeconomic factors including poverty and social isolation, access to and use of cooling, physiological and behavioral adaptation of the population, urban heat island effects, and urban infrastructure. [8.2.3, 8.2.4, 11.3.3, 11.3.4, 11.4.1, 11.7, 13.2.1, 19.3.2, 23.5.1, 25.3, 25.8.1, SREX Table SPM.1]
Climate information at the global scale	**Observed:** • *Very likely* decrease in the number of cold days and nights and increase in the number of warm days and nights, on the global scale between 1951 and 2010. [WGI AR5 2.6.1] • *Medium confidence* that the length and frequency of warm spells, including heat waves, has increased globally since 1950. [WGI AR5 2.6.1] **Projected:** *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase, for events defined as extremes on both daily and seasonal time scales. [WGI AR5 12.4.3]
Climate information at the regional scale	**Observed:** • *Likely* that heat wave frequency has increased since 1950 in large parts of Europe, Asia, and Australia. [WGI AR5 2.6.1] • *Medium confidence* in overall increase in heat waves and warm spells in North America since 1960. Insufficient evidence for assessment or spatially varying trends in heat waves or warm spells for South America and most of Africa. [SREX Table 3-2; WGI AR5 2.6.1] **Projected:** • *Likely* that, by the end of the 21st century under Representative Concentration Pathway 8.5 (RCP8.5) in most land regions, a current 20-year high-temperature event will at least double its frequency and in many regions occur every 2 years or annually, while a current 20-year low-temperature event will become exceedingly rare. [WGI AR5 12.4.3] • *Very likely* more frequent and/or longer heat waves or warm spells over most land areas. [WGI AR5 12.4.3]
Description	Heat-health early warning systems are instruments to prevent negative health impacts during heat waves. Weather forecasts are used to predict situations associated with increased mortality or morbidity. Components of effective heat wave and health warning systems include identifying weather situations that adversely affect human health, monitoring weather forecasts, communicating heat wave and prevention responses, targeting notifications to vulnerable populations, and evaluating and revising the system to increase effectiveness in a changing climate. Warning systems for heat waves have been planned and implemented broadly, for example in Europe, the United States, Asia, and Australia. [11.7.3, 24.4.6, 25.8.1, 26.6, Box 25-6]
Broader context	• Heat-health warning systems can be combined with other elements of a health protection plan, for example building capacity to support communities most at risk, supporting and funding health services, and distributing public health information. • In Africa, Asia, and elsewhere, early warning systems have been used to provide warning of and reduce a variety of risks related to famine and food insecurity; flooding and other weather-related hazards; exposure to air pollution from fire; and vector-borne and food-borne disease outbreaks. [7.5.1, 11.7, 15.4.2, 22.4.5, 24.4.6, 25.8.1, 26.6.3, Box 25-6]
Mangrove restoration to reduce flood risks and protect shorelines from storm surge	
Exposure and vulnerability	Loss of mangroves increases exposure of coastlines to storm surge, coastal erosion, saline intrusion, and tropical cyclones. Exposed infrastructure, livelihoods, and people are vulnerable to associated damage. Areas with development in the coastal zone, such as on small islands, can be particularly vulnerable. [5.4.3, 5.5.6, 29.7.2, Box CC-EA]
Climate information at the global scale	**Observed:** • *Likely* increase in the magnitude of extreme high sea level events since 1970, mostly explained by rising mean sea level. [WGI AR5 3.7.5] • *Low confidence* in long-term (centennial) changes in tropical cyclone activity, after accounting for past changes in observing capabilities. [WGI AR5 2.6.3] **Projected:** • *Very likely* significant increase in the occurrence of future sea level extremes by 2050 and 2100. [WGI AR5 13.7.2] • In the 21st century, *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged. *Likely* increase in both global mean tropical cyclone maximum wind speed and rainfall rates. [WGI AR5 14.6]
Climate information at the regional scale	**Observed:** Change in sea level relative to the land (relative sea level) can be significantly different from the global mean sea level change because of changes in the distribution of water in the ocean and vertical movement of the land. [WGI AR5 3.7.3] **Projected:** • *Low confidence* in region-specific projections of storminess and associated storm surges. [WGI AR5 13.7.2] • Projections of regional changes in sea level reach values of up to 30% above the global mean value in the Southern Ocean and around North America, and between 10% to 20% above the global mean value in equatorial regions. [WGI AR5 13.6.5] • *More likely than not* substantial increase in the frequency of the most intense tropical cyclones in the western North Pacific and North Atlantic. [WGI AR5 14.6]
Description	Mangrove restoration and rehabilitation has occurred in a number of locations (e.g., Vietnam, Djibouti, and Brazil) to reduce coastal flooding risks and protect shorelines from storm surge. Restored mangroves have been shown to attenuate wave height and thus reduce wave damage and erosion. They protect aquaculture industry from storm damage and reduce saltwater intrusion. [2.4.3, 5.5.4, 8.3.3, 22.4.5, 27.3.3]
Broader context	• Considered a low-regrets option benefiting sustainable development, livelihood improvement, and human well-being through improvements for food security and reduced risks from flooding, saline intrusion, wave damage, and erosion. Restoration and rehabilitation of mangroves, as well as of wetlands or deltas, is ecosystem-based adaptation that enhances ecosystem services. • Synergies with mitigation given that mangrove forests represent large stores of carbon. • Well-integrated ecosystem-based adaptation can be more cost effective and sustainable than non-integrated physical engineering approaches. [5.5, 8.4.2, 14.3.1, 24.6, 29.3.1, 29.7.2, 30.6.1, 30.6.2, Table 5-4, Box CC-EA]

Continued next page →

Table TS.2 (continued)

Community-based adaptation and traditional practices in small island contexts	
Exposure and vulnerability	With small land area, often low elevation coasts, and concentration of human communities and infrastructure in coastal zones, small islands are particularly vulnerable to rising sea levels and impacts such as inundation, saltwater intrusion, and shoreline change. [29.3.1, 29.3.3, 29.6.1, 29.6.2, 29.7.2]
Climate information at the global scale	**Observed:** • *Likely* increase in the magnitude of extreme high sea level events since 1970, mostly explained by rising mean sea level. [WGI AR5 3.7.5] • *Low confidence* in long-term (centennial) changes in tropical cyclone activity, after accounting for past changes in observing capabilities. [WGI AR5 2.6.3] • Since 1950 the number of heavy precipitation events over land has *likely* increased in more regions than it has decreased. [WGI AR5 2.6.2] **Projected:** • *Very likely* significant increase in the occurrence of future sea level extremes by 2050 and 2100. [WGI AR5 13.7.2] • In the 21st century, *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged. *Likely* increase in both global mean tropical cyclone maximum wind speed and rainfall rates. [WGI AR5 14.6] • Globally, for short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 12.4.5]
Climate information at the regional scale	**Observed:** Change in sea level relative to the land (relative sea level) can be significantly different from the global mean sea level change because of changes in the distribution of water in the ocean and vertical movement of the land. [WGI AR5 3.7.3] **Projected:** • *Low confidence* in region-specific projections of storminess and associated storm surges. [WGI AR5 13.7.2] • Projections of regional changes in sea level reach values of up to 30% above the global mean value in the Southern Ocean and around North America, and between 10% and 20% above the global mean value in equatorial regions. [WGI AR5 13.6.5] • *More likely than not* substantial increase in the frequency of the most intense tropical cyclones in the western North Pacific and North Atlantic. [WGI AR5 14.6]
Description	Traditional technologies and skills can be relevant for climate adaptation in small island contexts. In the Solomon Islands, relevant traditional practices include elevating concrete floors to keep them dry during heavy precipitation events and building low aerodynamic houses with palm leaves as roofing to avoid hazards from flying debris during cyclones, supported by perceptions that traditional construction methods are more resilient to extreme weather. In Fiji after Cyclone Ami in 2003, mutual support and risk sharing formed a central pillar for community-based adaptation, with unaffected households fishing to support those with damaged homes. Participatory consultations across stakeholders and sectors within communities and capacity building taking into account traditional practices can be vital to the success of adaptation initiatives in island communities, such as in Fiji or Samoa. [29.6.2]
Broader context	• Perceptions of self-efficacy and adaptive capacity in addressing climate stress can be important in determining resilience and identifying useful solutions. • The relevance of community-based adaptation principles to island communities, as a facilitating factor in adaptation planning and implementation, has been highlighted, for example, with focus on empowerment and learning-by-doing, while addressing local priorities and building on local knowledge and capacity. Community-based adaptation can include measures that cut across sectors and technological, social, and institutional processes, recognizing that technology by itself is only one component of successful adaptation. [5.5.4, 29.6.2]

Adaptive approaches to flood defense in Europe	
Exposure and vulnerability	Increased exposure of persons and property in flood risk areas has contributed to increased damages from flood events over recent decades. [5.4.3, 5.4.4, 5.5.5, 23.3.1, Box 5-1]
Climate information at the global scale	**Observed:** • *Likely* increase in the magnitude of extreme high sea level events since 1970, mostly explained by rising mean sea level. [WGI AR5 3.7.5] • Since 1950 the number of heavy precipitation events over land has *likely* increased in more regions than it has decreased. [WGI AR5 2.6.2] **Projected:** • *Very likely* that the time-mean rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971–2010 for all RCP scenarios. [WGI AR5 13.5.1] • Globally, for short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 12.4.5]
Climate information at the regional scale	**Observed:** • *Likely* increase in the frequency or intensity of heavy precipitation in Europe, with some seasonal and/or regional variations. [WGI AR5 2.6.2] • Increase in heavy precipitation in winter since the 1950s in some areas of northern Europe (*medium confidence*). Increase in heavy precipitation since the 1950s in some parts of west-central Europe and European Russia, especially in winter (*medium confidence*). [SREX Table 3-2] • Increasing mean sea level with regional variations, except in the Baltic Sea where the relative sea level is decreasing due to vertical crustal motion. [5.3.2, 23.2.2] **Projected:** • Over most of the mid-latitude land masses, extreme precipitation events will *very likely* be more intense and more frequent in a warmer world. [WGI AR5 12.4.5] • Overall precipitation increase in northern Europe and decrease in southern Europe (*medium confidence*). [23.2.2] • Increased extreme precipitation in northern Europe during all seasons, particularly winter, and in central Europe except in summer (*high confidence*). [23.2.2; SREX Table 3-3]
Description	Several governments have made ambitious efforts to address flood risk and sea level rise over the coming century. In the Netherlands, government recommendations include "soft" measures preserving land from development to accommodate increased river inundation; maintaining coastal protection through beach nourishment; and ensuring necessary political-administrative, legal, and financial resources. Through a multi-stage process, the British government has also developed extensive adaptation plans to adjust and improve flood defenses to protect London from future storm surges and river flooding. Pathways have been analyzed for different adaptation options and decisions, depending on eventual sea level rise, with ongoing monitoring of the drivers of risk informing decisions. [5.5.4, 23.7.1, Box 5-1]
Broader context	• The Dutch plan is considered a paradigm shift, addressing coastal protection by "working with nature" and providing "room for river." • The British plan incorporates iterative, adaptive decisions depending on the eventual sea level rise with numerous and diverse measures possible over the next 50 to 100 years to reduce risk to acceptable levels. • In cities in Europe and elsewhere, the importance of strong political leadership or government champions in driving successful adaptation action has been noted. [5.5.3, 5.5.4, 8.4.3, 23.7.1, 23.7.2, 23.7.4, Boxes 5-1 and 26-3]

Continued next page →

Table TS.2 (continued)

Index-based insurance for agriculture in Africa	
Exposure and vulnerability	Susceptibility to food insecurity and depletion of farmers' productive assets following crop failure. Low prevalence of insurance due to absent or poorly developed insurance markets or to amount of premium payments. The most marginalized and resource-poor especially may have limited ability to afford insurance premiums. [10.7.6, 13.3.2, Box 22-1]
Climate information at the global scale	**Observed:** • *Very likely* decrease in the number of cold days and nights and increase in the number of warm days and nights, on the global scale between 1951 and 2010. [WGI AR5 2.6.1] • *Medium confidence* that the length and frequency of warm spells, including heat waves, has increased globally since 1950. [WGI AR5 2.6.1] • Since 1950 the number of heavy precipitation events over land has *likely* increased in more regions than it has decreased. [WGI AR5 2.6.2] • *Low confidence* in a global-scale observed trend in drought or dryness (lack of rainfall). [WGI AR5 2.6.2] **Projected:** • *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase, for events defined as extremes on both daily and seasonal time scales. [WGI AR5 12.4.3] • Regional to global-scale projected decreases in soil moisture and increased risk of agricultural drought are *likely* in presently dry regions, and are projected with *medium confidence* by the end of this century under the RCP8.5 scenario. [WGI AR5 12.4.5] • Globally, for short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 12.4.5]
Climate information at the regional scale	**Observed:** • *Medium confidence* in increase in frequency of warm days and decrease in frequency of cold days and nights in southern Africa. [SREX Table 3-2] • *Medium confidence* in increase in frequency of warm nights in northern and southern Africa. [SREX Table 3-2] **Projected:** • *Likely* surface drying in southern Africa by the end of the 21st century under RCP8.5 (*high confidence*). [WGI AR5 12.4.5] • *Likely* increase in warm days and nights and decrease in cold days and nights in all regions of Africa (*high confidence*). Increase in warm days largest in summer and fall (*medium confidence*). [SREX Table 3-3] • *Likely* more frequent and/or longer heat waves and warm spells in Africa (*high confidence*). [SREX Table 3-3]
Description	A recently introduced mechanism that has been piloted in a number of rural locations, including in Malawi, Sudan, and Ethiopia, as well as in India. When physical conditions reach a particular predetermined threshold where significant losses are expected to occur—weather conditions such as excessively high or low cumulative rainfall or temperature peaks—the insurance pays out. [9.4.2, 13.3.2, 15.4.4, Box 22-1]
Broader context	• Index-based weather insurance is considered well suited to the agricultural sector in developing countries. • The mechanism allows risk to be shared across communities, with costs spread over time, while overcoming obstacles to traditional agricultural and disaster insurance markets. It can be integrated with other strategies such as microfinance and social protection programs. • Risk-based premiums can help encourage adaptive responses and foster risk awareness and risk reduction by providing financial incentives to policyholders to reduce their risk profile. • Challenges can be associated with limited availability of accurate weather data and difficulties in establishing which weather conditions cause losses. Basis risk (i.e., farmers suffer losses but no payout is triggered based on weather data) can promote distrust. There can also be difficulty in scaling up pilot schemes. • Insurance for work programs can enable cash-poor farmers to work for insurance premiums by engaging in community-identified disaster risk reduction projects. [10.7.4 to 10.7.6, 13.3.2, 15.4.4, Table 10-7, Boxes 22-1 and 25-7]

Continued next page →

for sea level rise has evolved considerably over the past 2 decades and shows a diversity of approaches, although its implementation remains piecemeal (*high confidence*). Adaptive capacity is generally high in many human systems, but implementation faces major constraints especially for transformational responses at local and community levels. [25.4, 25.10, Table 25-2, Boxes 25-1, 25-2, and 25-9]

- In North America, governments are engaging in incremental adaptation assessment and planning, particularly at the municipal level (*high confidence*). Some proactive adaptation is occurring to protect longer-term investments in energy and public infrastructure. [26.7 to 26.9]
- In Central and South America, ecosystem-based adaptation including protected areas, conservation agreements, and community management of natural areas is occurring (*high confidence*). Resilient crop varieties, climate forecasts, and integrated water resources management are being adopted within the agricultural sector in some areas. [27.3]
- In the Arctic, some communities have begun to deploy adaptive co-management strategies and communications infrastructure, combining traditional and scientific knowledge (*high confidence*). [28.2, 28.4]
- In small islands, which have diverse physical and human attributes, community-based adaptation has been shown to generate larger benefits when delivered in conjunction with other development activities (*high confidence*). [29.3, 29.6, Table 29-3, Figure 29-1]
- In both the open ocean and coastal areas, international cooperation and marine spatial planning are starting to facilitate adaptation to climate change, with constraints from challenges of spatial scale and governance issues (*high confidence*). Observed coastal adaptation includes major projects (e.g., Thames Estuary, Venice Lagoon, Delta Works) and specific practices in some countries (e.g., Netherlands, Australia, Bangladesh). [5.5, 7.3, 15.4, 30.6, Box CC-EA]

Table TS.2 presents examples of how climate extremes and change, as well as exposure and vulnerability at the scale of risk management, shape adaptation actions and approaches to reducing vulnerability and enhancing resilience.

A-3. The Decision-making Context

Climate variability and extremes have long been important in many decision-making contexts. Climate-related risks are now evolving over

Table TS.2 (continued)

Relocation of agricultural industries in Australia	
Exposure and vulnerability	Crops sensitive to changing patterns of temperature, rainfall, and water availability. [7.3, 7.5.2]
Climate information at the global scale	**Observed:** • *Very likely* decrease in the number of cold days and nights and increase in the number of warm days and nights, on the global scale between 1951 and 2010. [WGI AR5 2.6.1] • *Medium confidence* that the length and frequency of warm spells, including heat waves, has increased globally since 1950. [WGI AR5 2.6.1] • *Medium confidence* in precipitation change over global land areas since 1950. [WGI AR5 2.5.1] • Since 1950 the number of heavy precipitation events over land has *likely* increased in more regions than it has decreased. [WGI AR5 2.6.2] • *Low confidence* in a global-scale observed trend in drought or dryness (lack of rainfall). [WGI AR5 2.6.2] **Projected:** • *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase, for events defined as extremes on both daily and seasonal time scales. [WGI AR5 12.4.3] • *Virtually certain* increase in global precipitation as global mean surface temperature increases. [WGI AR5 12.4.1] • Regional to global-scale projected decreases in soil moisture and increased risk of agricultural drought are *likely* in presently dry regions, and are projected with *medium confidence* by the end of this century under the RCP8.5 scenario. [WGI AR5 12.4.5] • Globally, for short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 12.4.5]
Climate information at the regional scale	**Observed:** • Cool extremes rarer and hot extremes more frequent and intense over Australia and New Zealand, since 1950 (*high confidence*). [Table 25-1] • *Likely* increase in heat wave frequency since 1950 in large parts of Australia. [WGI AR5 2.6.1] • Late autumn/winter decreases in precipitation in southwestern Australia since the 1970s and southeastern Australia since the mid-1990s, and annual increases in precipitation in northwestern Australia since the 1950s (*very high confidence*). [Table 25-1] • Mixed or insignificant trends in annual daily precipitation extremes, but a tendency to significant increase in annual intensity of heavy precipitation in recent decades for sub-daily events in Australia (*high confidence*). [Table 25-1] **Projected:** • Hot days and nights more frequent and cold days and nights less frequent during the 21st century in Australia and New Zealand (*high confidence*). [Table 25-1] • Annual decline in precipitation over southwestern Australia (*high confidence*) and elsewhere in southern Australia (*medium confidence*). Reductions strongest in the winter half-year (*high confidence*). [Table 25-1] • Increase in most regions in the intensity of rare daily rainfall extremes and in sub-daily extremes (*medium confidence*) in Australia and New Zealand. [Table 25-1] • Drought occurrence to increase in southern Australia (*medium confidence*). [Table 25-1] • Snow depth and snow area to decline in Australia (*very high confidence*). [Table 25-1] • Freshwater resources projected to decline in far southeastern and far southwestern Australia (*high confidence*). [25.5.2]
Description	Industries and individual farmers are relocating parts of their operations, for example for rice, wine, or peanuts in Australia, or are changing land use *in situ* in response to recent climate change or expectations of future change. For example, there has been some switching from grazing to cropping in southern Australia. Adaptive movement of crops has also occurred elsewhere. [7.5.1, 25.7.2, Table 9-7, Box 25-5]
Broader context	• Considered transformational adaptation in response to impacts of climate change. • Positive or negative implications for the wider communities in origin and destination regions. [25.7.2, Box 25-5]

time due to both climate change and development. This section builds from existing experience with decision making and risk management. It creates a foundation for understanding the report's assessment of future climate-related risks and potential responses.

Responding to climate-related risks involves decision making in a changing world, with continuing uncertainty about the severity and timing of climate-change impacts and with limits to the effectiveness of adaptation (*high confidence*). Iterative risk management is a useful framework for decision making in complex situations characterized by large potential consequences, persistent uncertainties, long timeframes, potential for learning, and multiple climatic and non-climatic influences changing over time. See Figure TS.4. Assessment of the widest possible range of potential impacts, including low-probability outcomes with large consequences, is central to understanding the benefits and trade-offs of alternative risk management actions. The complexity of adaptation actions across scales and contexts means that monitoring and learning are important components of effective adaptation. [2.1 to 2.4, 3.6, 14.1 to 14.3, 15.2 to 15.4, 16.2 to 16.4, 17.1 to 17.3, 17.5, 20.6, 22.4, 25.4, Figure 1-5]

Adaptation and mitigation choices in the near term will affect the risks of climate change throughout the 21st century (*high confidence*). Figure TS.5 illustrates projected climate futures under a low-emission mitigation scenario and a high-emission scenario [Representative Concentration Pathways (RCPs) 2.6 and 8.5], along with observed temperature and precipitation changes. The benefits of adaptation and mitigation occur over different but overlapping timeframes. Projected global temperature increase over the next few decades is similar across emission scenarios (Figure TS.5A, middle panel) (WGI AR5 Section 11.3). During this near-term era of committed climate change, risks will evolve as socioeconomic trends interact with the changing climate. Societal responses, particularly adaptations, will influence near-term outcomes. In the second half of the 21st century and beyond, global temperature increase diverges across emission scenarios (Figure TS.5A, middle and bottom panels) (WGI AR5 Section 12.4 and Table SPM.2). For this longer-term era of climate options, near-term and longer-term adaptation and mitigation, as well as development pathways, will determine the risks of climate change. [2.5, 21.2, 21.3, 21.5, Box CC-RC]

Assessment of risks in the WGII AR5 relies on diverse forms of evidence. Expert judgment is used to integrate evidence into evaluations of risks. Forms of evidence include, for example, empirical observations, experimental results, process-based understanding, statistical approaches, and simulation and descriptive models. Future

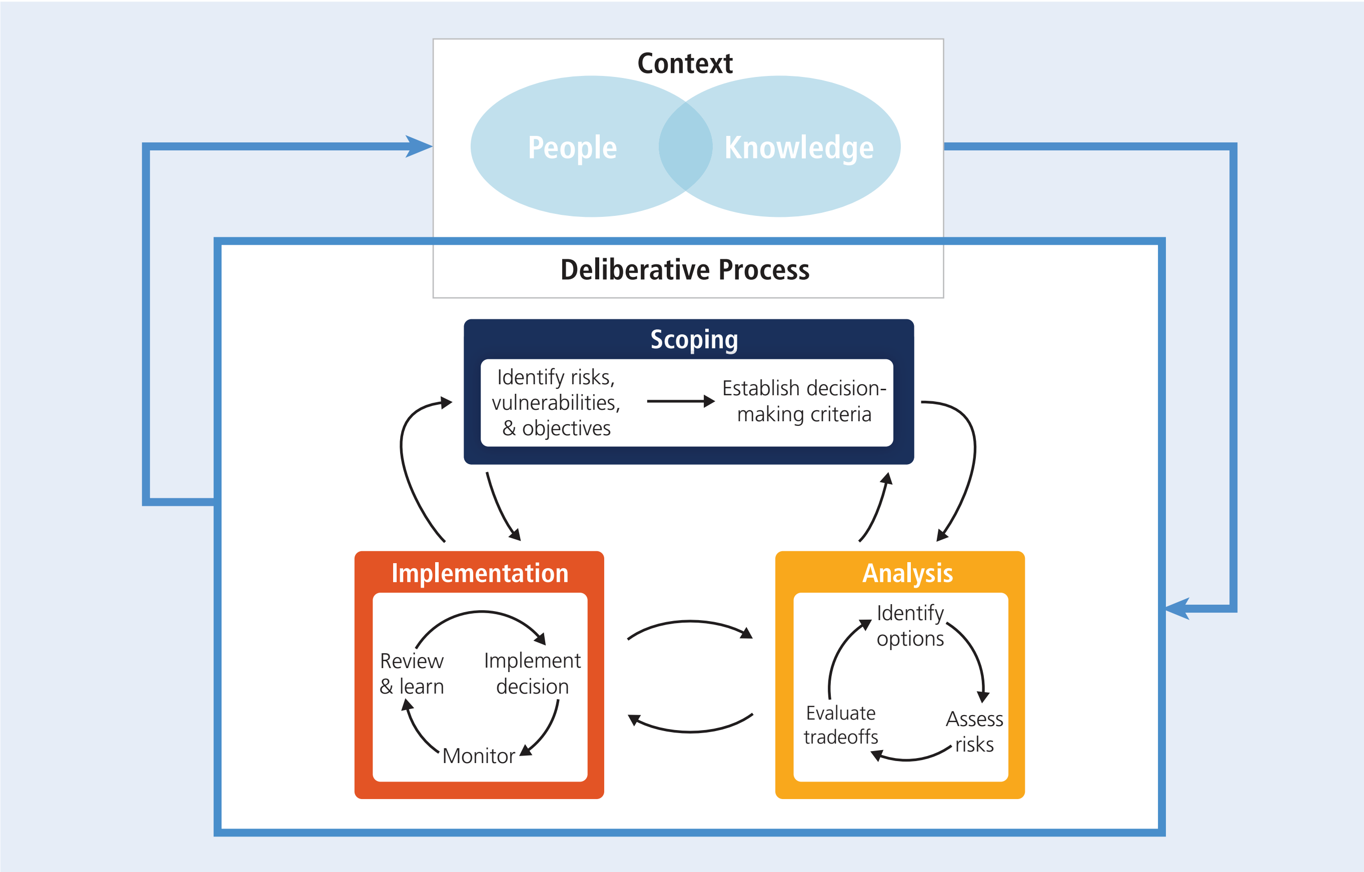


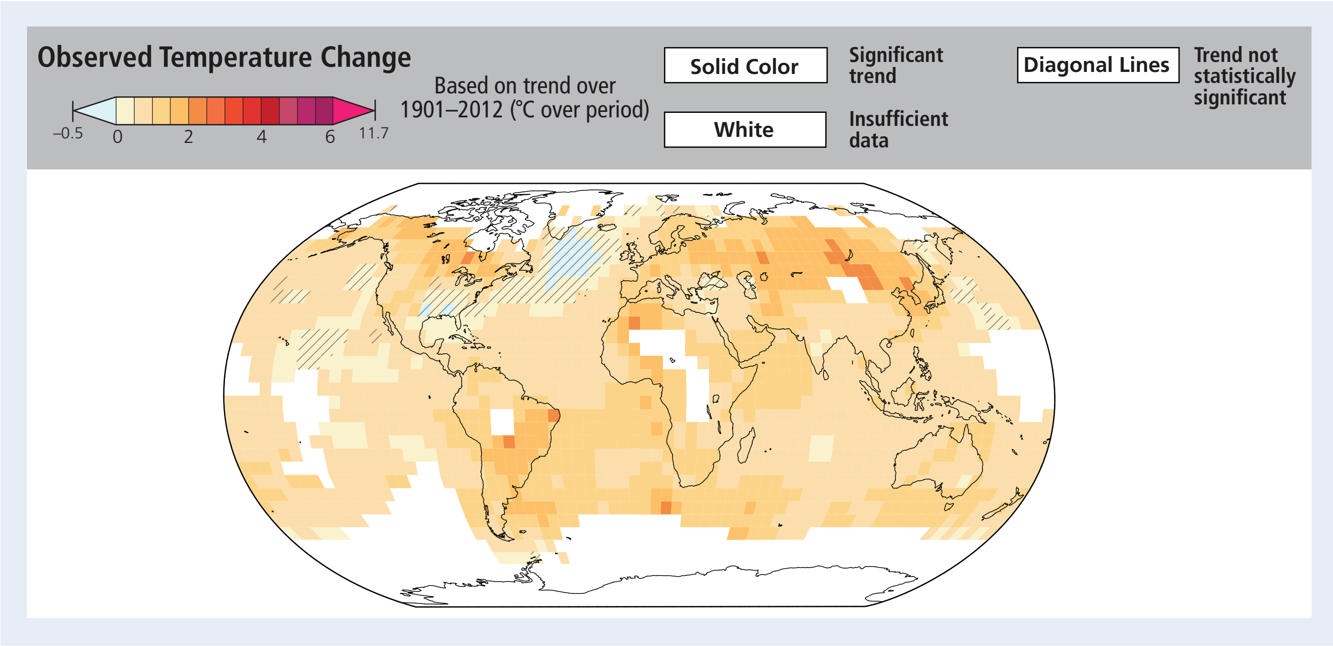
Figure TS.4 | Climate-change adaptation as an iterative risk management process with multiple feedbacks. People and knowledge shape the process and its outcomes. [Figure 2-1]

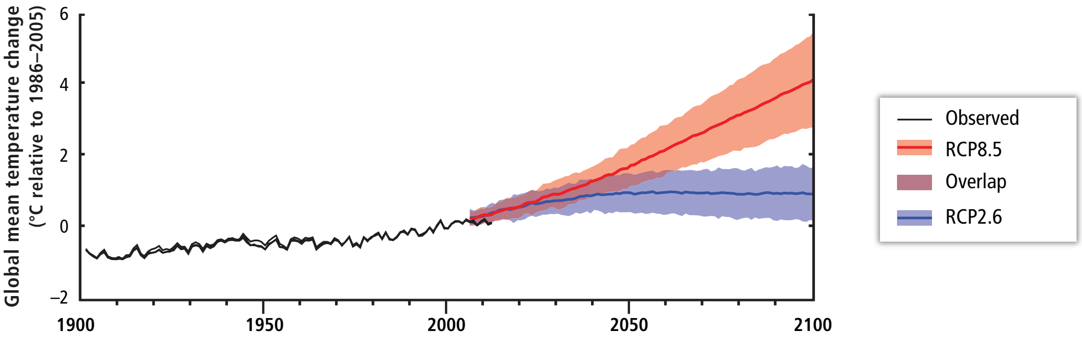
risks related to climate change vary substantially across plausible alternative development pathways, and the relative importance of development and climate change varies by sector, region, and time period (*high confidence*). Scenarios are useful tools for characterizing possible future socioeconomic pathways, climate change and its risks, and policy implications. Climate-model projections informing evaluations of risks in this report are generally based on the RCPs (Figure TS.5), as well as the older IPCC *Special Report on Emissions Scenarios* (SRES) scenarios. [1.1, 1.3, 2.2, 2.3, 19.6, 20.2, 21.3, 21.5, 26.2, Box CC-RC; WGI AR5 Box SPM.1]

Scenarios can be divided into those that explore how futures may unfold under various drivers (problem exploration) and those that test how various interventions may play out (solution exploration) (*robust evidence*, *high agreement*). Adaptation approaches address uncertainties associated with future climate and socioeconomic conditions and with the diversity of specific contexts (*medium evidence*, *high agreement*). Although many national studies identify a variety of strategies and approaches for adaptation, they can be classified into two broad categories: "top-down" and "bottom-up" approaches. The top-down approach is a scenario-impact approach, consisting of downscaled climate projections, impact assessments, and formulation of strategies and options. The bottom-up approach is a vulnerability-threshold approach, starting with the identification of vulnerabilities, sensitivities, and thresholds for specific sectors or communities. Iterative assessments of impacts and adaptation in the top-down approach and building adaptive capacity of local communities are typical strategies for responding to uncertainties. [2.2, 2.3, 15.3]

Uncertainties about future vulnerability, exposure, and responses of interlinked human and natural systems are large (*high confidence*). This motivates exploration of a wide range of socioeconomic futures in assessments of risks. Understanding future vulnerability, exposure, and response capacity of interlinked human and natural systems is challenging due to the number of interacting social, economic, and cultural factors, which have been incompletely considered to date. These factors include wealth and its distribution across society, demographics, migration, access to technology and information, employment patterns, the quality of adaptive responses, societal values, governance structures, and institutions to resolve conflicts. International dimensions such as trade and relations among states are also important for understanding the risks of climate change at regional scales. [11.3, 12.6, 21.3 to 21.5, 25.3, 25.4, 25.11, 26.2]

(A)





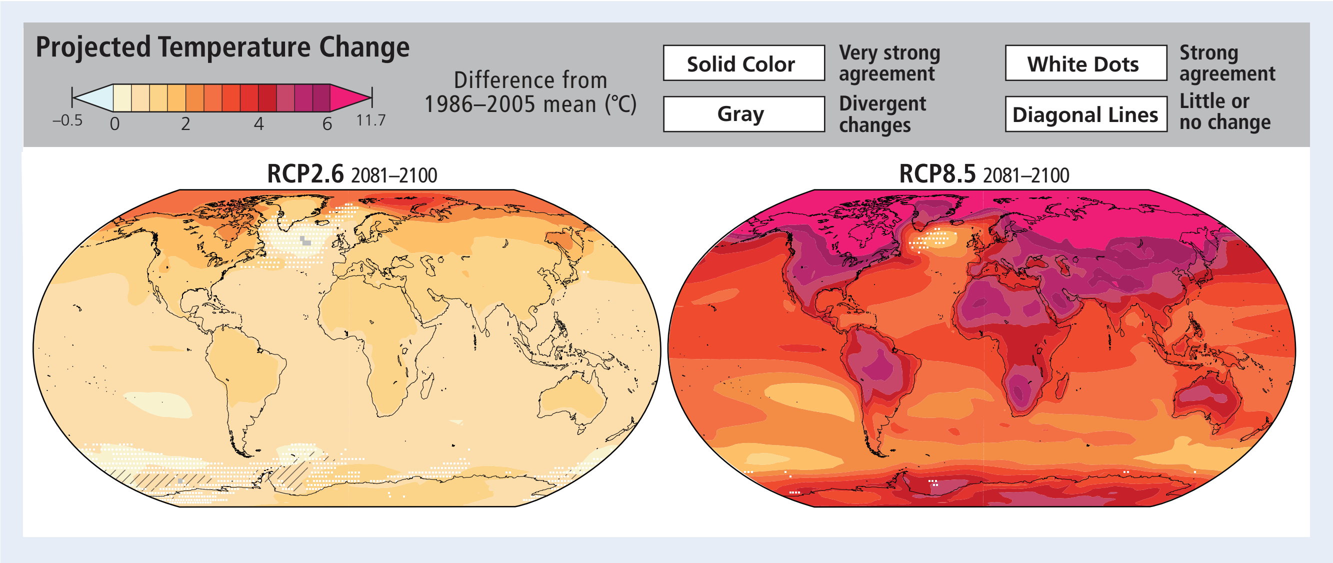


Figure TS.5

Continued next page →

Figure TS.5 (continued)

(B)

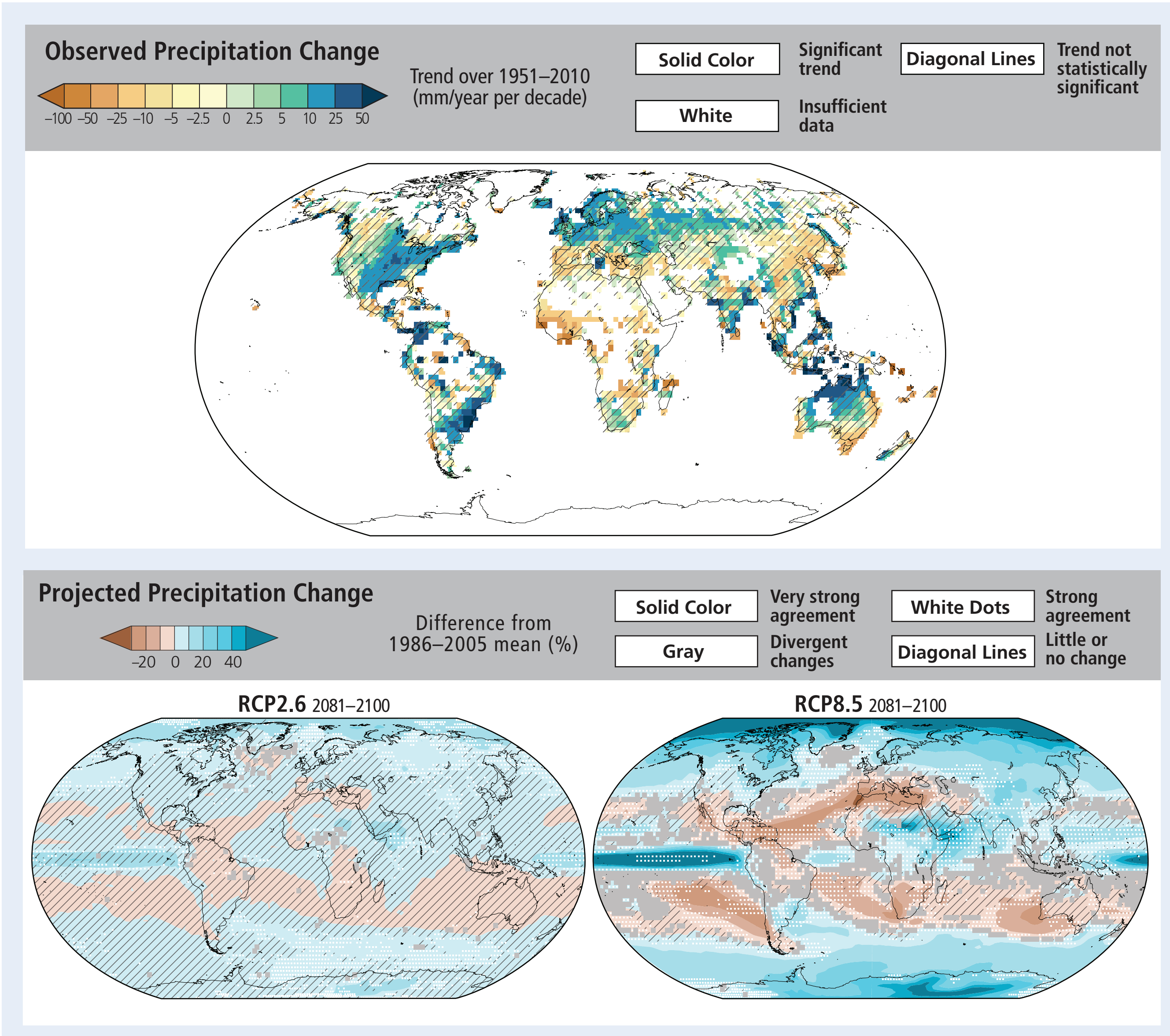


Figure TS.5 | Observed and projected changes in annual average surface temperature (A) and precipitation (B). This figure informs understanding of climate-related risks in the WGII AR5. It illustrates changes observed to date and projected changes under continued high emissions and under ambitious mitigation.

Technical details: (A, top panel) Map of observed annual mean temperature change from 1901–2012, derived from a linear trend. Observed data (range of grid-point values: –0.53 to 2.50°C over period) are from WGI AR5 Figures SPM.1 and 2.21. (B, top panel) Map of observed annual precipitation change from 1951–2010, derived from a linear trend. Observed data (range of grid-point values: –185 to 111 mm/year per decade) are from WGI AR5 Figures SPM.2 and 2.29. For observed temperature and precipitation, trends have been calculated where sufficient data permit a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where trends are significant at the 10% level. Diagonal lines indicate areas where trends are not significant. (A, middle panel) Observed and projected future global annual mean temperature relative to 1986–2005. Observed warming from 1850–1900 to 1986–2005 is 0.61°C (5–95% confidence interval: 0.55 to 0.67°C). Black lines show temperature estimates from three datasets. Blue and red lines and shading denote the ensemble mean and ±1.64 standard deviation range, based on Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations from 32 models for RCP2.6 and 39 models for RCP8.5. (A and B, bottom panel) CMIP5 multi-model mean projections of annual mean temperature changes (A) and mean percent changes in annual mean precipitation (B) for 2081–2100 under RCP2.6 and 8.5, relative to 1986–2005. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability (natural internal variability in 20-yr means) and ≥90% of models agree on sign of change. Colors with white dots indicate areas with strong agreement, where ≥66% of models show change greater than the baseline variability and ≥66% of models agree on sign of change. Gray indicates areas with divergent changes, where ≥66% of models show change greater than the baseline variability, but <66% agree on sign of change. Colors with diagonal lines indicate areas with little or no change, where <66% of models show change greater than the baseline variability, although there may be significant change at shorter timescales such as seasons, months, or days. For temperature projections, analysis uses model data (range of grid-point values across RCP2.6 and 8.5: 0.06 to 11.71°C) from WGI AR5 Figure SPM.8. For precipitation projections, analysis uses model data (range of grid-point values: –9 to 22% for RCP2.6 and –34 to 112% for RCP8.5) from WGI AR5 Figure SPM.8, Box 12.1, and Annex I. For a full description of methods, see Box CC-RC. See also Annex I of WGI AR5. [Boxes 21-2 and CC-RC; WGI AR5 2.4 and 2.5, Figures SPM.1, SPM.2, SPM.7, SPM.8, 2.21, and 2.29]

B: FUTURE RISKS AND OPPORTUNITIES FOR ADAPTATION

This section presents future risks and more limited potential benefits across sectors and regions, examining how they are affected by the magnitude and rate of climate change and by socioeconomic choices. It also assesses opportunities for reducing impacts and managing risks through adaptation and mitigation. The section examines the distribution of risks across populations with contrasting vulnerability and adaptive capacity, across sectors where metrics for quantifying impacts may be quite different, and across regions with varying traditions and resources. The assessment features interactions across sectors and regions and among climate change and other stressors. For different sectors and regions, the section describes risks and potential benefits over the next few decades, the near-term era of committed climate change. Over this timeframe, projected global temperature increase is similar across emission scenarios. The section also provides information on risks and potential benefits in the second half of the 21st century and beyond, the longer-term era of climate options. Over this longer term, global temperature increase diverges across emission scenarios, and the assessment distinguishes potential outcomes for 2°C and 4°C global mean temperature increase above preindustrial levels. The section elucidates how and when choices matter in reducing future risks, highlighting the differing timeframes for mitigation and adaptation benefits.

B-1. Key Risks across Sectors and Regions

Key risks are potentially severe impacts relevant to Article 2 of the UN Framework Convention on Climate Change, which refers to "dangerous anthropogenic interference with the climate system." Risks are considered key due to high hazard or high vulnerability of societies and systems exposed, or both. Identification of key risks was based on expert judgment using the following specific criteria: large magnitude, high probability, or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation. Key risks are integrated into five complementary and overarching reasons for concern (RFCs) in Box TS.5.

The key risks that follow, all of which are identified with *high confidence*, span sectors and regions. Each of these key risks contributes to one or more RFCs. Roman numerals correspond to entries in Table TS.3, which further illustrates relevant examples and interactions. [19.2 to 19.4, 19.6, Table 19-4, Boxes 19-2 and CC-KR]

i) Risk of death, injury, ill-health, or disrupted livelihoods in low-lying coastal zones and small island developing states and other small islands, due to storm surges, coastal flooding, and sea level rise. See RFCs 1 to 5. [5.4, 8.2, 13.2, 19.2 to 19.4, 19.6, 19.7, 24.4, 24.5, 26.7, 26.8, 29.3, 30.3, Tables 19-4 and 26-1, Figure 26-2, Boxes 25-1, 25-7, and CC-KR]

Table TS.3 | A selection of the hazards, key vulnerabilities, key risks, and emergent risks identified in chapters of this report. The examples underscore the complexity of risks determined by various interacting climate-related hazards, non-climatic stressors, and multifaceted vulnerabilities (see also Figure TS.1). Vulnerabilities identified as key arise when exposure to hazards combines with social, institutional, economic, or environmental vulnerability, as indicated by icons in the table. Emergent risks arise from complex system interactions. Roman numerals correspond with key risks listed in Section B-1. [19.6, Table 19-4]

No.	Hazard	Key vulnerabilities	Key risks	Emergent risks
i	Sea level rise and coastal flooding including storm surges [5.4.3, 8.1.4, 8.2.3, 8.2.4, 13.1.4, 13.2.2, 24.4, 24.5, 26.7, 26.8, 29.3, 30.3.1, Boxes 25-1 and 25-7; WGI AR5 3.7, 13.5, Table 13-5]	High exposure of people, economic activity, and infrastructure in low-lying coastal zones and Small Island Developing States (SIDS) and other small islands Urban population unprotected due to substandard housing and inadequate insurance. Marginalized rural population with multidimensional poverty and limited alternative livelihoods Insufficient local governmental attention to disaster risk reduction	Death, injury, and disruption to livelihoods, food supplies, and drinking water Loss of common-pool resources, sense of place, and identity, especially among indigenous populations in rural coastal zones	Interaction of rapid urbanization, sea level rise, increasing economic activity, disappearance of natural resources, and limits of insurance; burden of risk management shifted from the state to those at risk leading to greater inequality
ii	Extreme precipitation and inland flooding [3.2.7, 3.4.8, 8.2.3, 8.2.4, 13.2.1, 25.10, 26.3, 26.7, 26.8, 27.3.5, Box 25-8; WGI AR5 11.3.2]	Large numbers of people exposed in urban areas to flood events, particularly in low-income informal settlements Overwhelmed, aging, poorly maintained, and inadequate urban drainage infrastructure and limited ability to cope and adapt due to marginalization, high poverty, and culturally imposed gender roles Inadequate governmental attention to disaster risk reduction	Death, injury, and disruption of human security, especially among children, elderly, and disabled persons	Interaction of increasing frequency of intense precipitation, urbanization, and limits of insurance; burden of risk management shifted from the state to those at risk leading to greater inequality, eroded assets due to infrastructure damage, abandonment of urban districts, and the creation of high risk/high poverty spatial traps
iii	Novel hazards yielding systemic risks [8.1.4, 8.2.4, 10.2, 10.3, 12.6, 23.9, 25.10, 26.7, 26.8; WGI AR5 11.3.2]	Populations and infrastructure exposed and lacking historical experience with these hazards Overly hazard-specific management planning and infrastructure design, and/or low forecasting capability	Failure of systems coupled to electric power system, e.g., drainage systems reliant on electric pumps or emergency services reliant on telecommunications. Collapse of health and emergency services in extreme events	Interactions due to dependence on coupled systems lead to magnification of impacts of extreme events. Reduced social cohesion due to loss of faith in management institutions undermines preparation and capacity for response.
iv	Increasing frequency and intensity of extreme heat, including urban heat island effect [8.2.3, 11.3, 11.4.1, 13.2, 23.5.1, 24.4.6, 25.8.1, 26.6, 26.8, Box CC-HS; WGI AR5 11.3.2]	Increasing urban population of the elderly, the very young, expectant mothers, and people with chronic health problems in settlements subject to higher temperatures Inability of local organizations that provide health, emergency, and social services to adapt to new risk levels for vulnerable groups	Increased mortality and morbidity during periods of extreme heat	Interaction of demographic shifts with changes in regional temperature extremes, local heat island, and air pollution Overloading of health and emergency services. Higher mortality, morbidity, and productivity loss among manual workers in hot climates

Table TS.3 (continued)

No.	Hazard	Key vulnerabilities	Key risks	Emergent risks
v	Warming, drought, and precipitation variability [7.3 to 7.5, 11.3, 11.6.1, 13.2, 19.3.2, 19.4.1, 22.3.4, 24.4, 26.8, 27.3.4; WGI AR5 11.3.2]	Poorer populations in urban and rural settings are susceptible to resulting food insecurity; includes particularly farmers who are net food buyers and people in low-income, agriculturally dependent economies that are net food importers. Limited ability to cope among the elderly and female-headed households	Risk of harm and loss of life due to reversal of progress in reducing malnutrition	Interactions of climate changes, population growth, reduced productivity, biofuel crop cultivation, and food prices with persistent inequality, and ongoing food insecurity for the poor increase malnutrition, giving rise to larger burden of disease. Exhaustion of social networks reduces coping capacity.
vi	Drought [3.2.7, 3.4.8, 3.5.1, 8.2.3, 8.2.4, 9.3.3, 9.3.5, 13.2.1, 19.3.2, 24.4, 25.7, Box 25-5; WGI AR5 12.4.1, 12.4.5]	Urban populations with inadequate water services. Existing water shortages (and irregular supplies), and constraints on increasing supplies Lack of capacity and resilience in water management regimes including rural–urban linkages	Insufficient water supply for people and industry yielding severe harm and economic impacts	Interaction of urbanization, infrastructure insufficiency, groundwater depletion
		Poorly endowed farmers in drylands or pastoralists with insufficient access to drinking and irrigation water Limited ability to compensate for losses in water-dependent farming and pastoral systems, and conflict over natural resources Lack of capacity and resilience in water management regimes, inappropriate land policy, and misperception and undermining of pastoral livelihoods	Loss of agricultural productivity and/or income of rural people. Destruction of livelihoods particularly for those depending on water-intensive agriculture. Risk of food insecurity	Interactions across human vulnerabilities: deteriorating livelihoods, poverty traps, heightened food insecurity, decreased land productivity, rural outmigration, and increase in new urban poor in developing countries. Potential tipping point in rain-fed farming system and/or pastoralism
vii	Rising ocean temperature, ocean acidification, and loss of Arctic sea ice [5.4.2, 6.3.1, 6.3.2, 7.4.2, 9.3.5, 22.3.2, 24.4, 25.6, 27.3.3, 28.2, 28.3, 29.3.1, 30.5, 30.6, Boxes CC-OA and CC-CR; WGI AR5 11.3.3]	High susceptibility of warm-water coral reefs and respective ecosystem services for coastal communities; high susceptibility of polar systems, e.g., to invasive species Susceptibility of coastal and SIDS fishing communities depending on these ecosystem services; and of Arctic settlements and culture	Loss of coral cover, Arctic species, and associated ecosystems with reduction of biodiversity and potential losses of important ecosystem services. Risk of loss of endemic species, mixing of ecosystem types, and increased dominance of invasive organisms	Interactions of stressors such as acidification and warming on calcareous organisms enhancing risk
viii	Rising land temperatures, and changes in precipitation patterns and in frequency and intensity of extreme heat [4.3.4, 19.3.2, 22.4.5, 27.3, Boxes 23-1 and CC-WE; WGI AR5 11.3.2]	Susceptibility of human systems, agro-ecosystems, and natural ecosystems to (1) loss of regulation of pests and diseases, fire, landslide, erosion, flooding, avalanche, water quality, and local climate; (2) loss of provision of food, livestock, fiber, and bioenergy; (3) loss of recreation, tourism, aesthetic and heritage values, and biodiversity	Reduction of biodiversity and potential losses of important ecosystem services. Risk of loss of endemic species, mixing of ecosystem types, and increased dominance of invasive organisms	Interaction of social-ecological systems with loss of ecosystem services on which they depend

ii) Risk of severe ill-health and disrupted livelihoods for large urban populations due to inland flooding in some regions. See RFCs 2 and 3. [3.4, 3.5, 8.2, 13.2, 19.6, 25.10, 26.3, 26.8, 27.3, Tables 19-4 and 26-1, Boxes 25-8 and CC-KR]

iii) Systemic risks due to extreme weather events leading to breakdown of infrastructure networks and critical services such as electricity, water supply, and health and emergency services. See RFCs 2 to 4. [5.4, 8.1, 8.2, 9.3, 10.2, 10.3, 12.6, 19.6, 23.9, 25.10, 26.7, 26.8, 28.3, Table 19-4, Boxes CC-KR and CC-HS]

iv) Risk of mortality and morbidity during periods of extreme heat, particularly for vulnerable urban populations and those working outdoors in urban or rural areas. See RFCs 2 and 3. [8.1, 8.2, 11.3, 11.4, 11.6, 13.2, 19.3, 19.6, 23.5, 24.4, 25.8, 26.6, 26.8, Tables 19-4 and 26-1, Boxes CC-KR and CC-HS]

v) Risk of food insecurity and the breakdown of food systems linked to warming, drought, flooding, and precipitation variability and extremes, particularly for poorer populations in urban and rural settings. See RFCs 2 to 4. [3.5, 7.4, 7.5, 8.2, 8.3, 9.3, 11.3, 11.6, 13.2, 19.3, 19.4, 19.6, 22.3, 24.4, 25.5, 25.7, 26.5, 26.8, 27.3, 28.2, 28.4, Table 19-4, Box CC-KR]

vi) Risk of loss of rural livelihoods and income due to insufficient access to drinking and irrigation water and reduced agricultural productivity, particularly for farmers and pastoralists with minimal capital in semi-arid regions. See RFCs 2 and 3. [3.4, 3.5, 9.3, 12.2, 13.2, 19.3, 19.6, 24.4, 25.7, 26.8, Table 19-4, Boxes 25-5 and CC-KR]

vii) Risk of loss of marine and coastal ecosystems, biodiversity, and the ecosystem goods, functions, and services they provide for coastal livelihoods, especially for fishing communities in the tropics and the

Box TS.5 | Human Interference with the Climate System

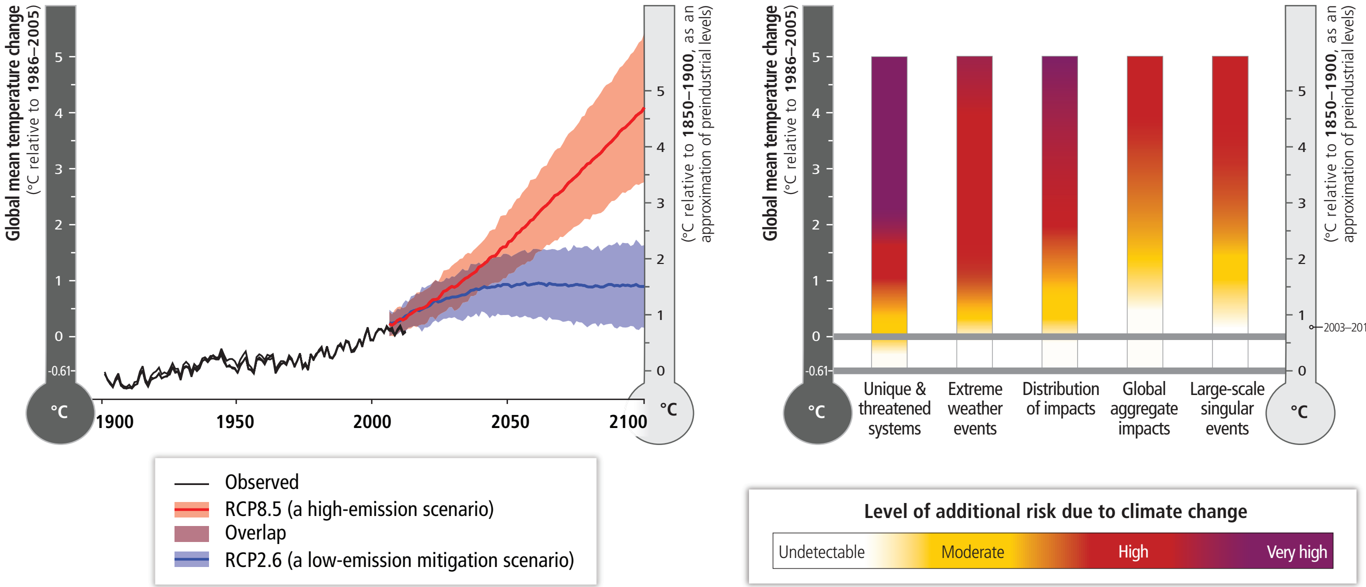
Human influence on the climate system is clear (WGI AR5 SPM Section D.3; WGI AR5 Sections 2.2, 6.3, 10.3 to 10.6, 10.9). Yet determining whether such influence constitutes "dangerous anthropogenic interference" in the words of Article 2 of the UNFCCC involves both risk assessment and value judgments. Scientific assessment can characterize risks based on the likelihood, magnitude, and scope of potential consequences of climate change. Science can also evaluate risks varying spatially and temporally across alternative development pathways, which affect vulnerability, exposure, and level of climate change. Interpreting the potential danger of risks, however, also requires value judgments by people with differing goals and worldviews. Judgments about the risks of climate change depend on the relative importance ascribed to economic versus ecosystem assets, to the present versus the future, and to the distribution versus aggregation of impacts. From some perspectives, isolated or infrequent impacts from climate change may not rise to the level of dangerous anthropogenic interference, but accumulation of the same kinds of impacts could, as they become more widespread, more frequent, or more severe. The rate of climate change can also influence risks. This report assesses risks across contexts and through time, providing a basis for judgments about the level of climate change at which risks become dangerous.

Five integrative reasons for concern (RFCs) provide a framework for summarizing key risks across sectors and regions. First identified in the IPCC Third Assessment Report, the RFCs illustrate the implications of warming and of adaptation limits for people, economies, and ecosystems. They provide one starting point for evaluating dangerous anthropogenic interference with the climate system. Risks for each RFC, updated based on assessment of the literature and expert judgments, are presented below and in Box TS.5 Figure 1. All temperatures below are given as global average temperature change relative to 1986–2005 ("recent").[1] [18.6, 19.6]

1) **Unique and threatened systems**: Some unique and threatened systems, including ecosystems and cultures, are already at risk from climate change (*high confidence*). The number of such systems at risk of severe consequences is higher with additional warming of around 1°C. Many species and systems with limited adaptive capacity are subject to very high risks with additional warming of 2°C, particularly Arctic-sea-ice and coral-reef systems.
2) **Extreme weather events**: Climate-change-related risks from extreme events, such as heat waves, extreme precipitation, and coastal flooding, are already moderate (*high confidence*) and high with 1°C additional warming (*medium confidence*). Risks associated with some types of extreme events (e.g., extreme heat) increase further at higher temperatures (*high confidence*).
3) **Distribution of impacts**: Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. Risks are already moderate because of regionally differentiated climate-change impacts on crop production in particular (*medium* to *high confidence*). Based on projected decreases in regional crop yields and water availability, risks of unevenly distributed impacts are high for additional warming above 2°C (*medium confidence*).
4) **Global aggregate impacts**: Risks of global aggregate impacts are moderate for additional warming between 1–2°C, reflecting impacts to both Earth's biodiversity and the overall global economy (*medium confidence*). Extensive biodiversity loss with associated loss of ecosystem goods and services results in high risks around 3°C additional warming (*high confidence*). Aggregate economic damages accelerate with increasing temperature (*limited evidence*, *high agreement*), but few quantitative estimates have been completed for additional warming around 3°C or above.
5) **Large-scale singular events**: With increasing warming, some physical systems or ecosystems may be at risk of abrupt and irreversible changes. Risks associated with such tipping points become moderate between 0–1°C additional warming, due to early warning signs that both warm-water coral reef and Arctic ecosystems are already experiencing irreversible regime shifts (*medium confidence*). Risks increase disproportionately as temperature increases between 1–2°C additional warming and become high above 3°C, due to the potential for a large and irreversible sea level rise from ice sheet loss. For sustained warming greater than some threshold,[2] near-complete loss of the Greenland ice sheet would occur over a millennium or more, contributing up to 7 m of global mean sea level rise.

Continued next page →

[1] Observed warming from 1850–1900 to 1986–2005 is 0.61°C (5–95% confidence interval: 0.55 to 0.67°C). [WGI AR5 2.4]
[2] Current estimates indicate that this threshold is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) sustained global mean warming above preindustrial levels. [WGI AR5 SPM, 5.8, 13.4, 13.5]



Box TS.5 Figure 1 | A global perspective on climate-related risks. Risks associated with reasons for concern are shown at right for increasing levels of climate change. The color shading indicates the additional risk due to climate change when a temperature level is reached and then sustained or exceeded. Undetectable risk (white) indicates no associated impacts are detectable and attributable to climate change. Moderate risk (yellow) indicates that associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks. High risk (red) indicates severe and widespread impacts, also accounting for the other specific criteria for key risks. Purple, introduced in this assessment, shows that very high risk is indicated by all specific criteria for key risks. [Figure 19-4] For reference, past and projected global annual average surface temperature is shown at left, as in Figure TS.5. [Figure RC-1, Box CC-RC; WGI AR5 Figures SPM.1 and SPM.7] Based on the longest global surface temperature dataset available, the observed change between the average of the period 1850–1900 and of the AR5 reference period (1986–2005) is 0.61°C (5–95% confidence interval: 0.55 to 0.67°C) [WGI AR5 SPM, 2.4], which is used here as an approximation of the change in global mean surface temperature since preindustrial times, referred to as the period before 1750. [WGI and WGII AR5 glossaries]

Arctic. See RFCs 1, 2, and 4. [5.4, 6.3, 7.4, 9.3, 19.5, 19.6, 22.3, 25.6, 27.3, 28.2, 28.3, 29.3, 30.5 to 30.7, Table 19-4, Boxes CC-OA, CC-CR, CC-KR, and CC-HS]

viii) Risk of loss of terrestrial and inland water ecosystems, biodiversity, and the ecosystem goods, functions, and services they provide for livelihoods. See RFCs 1, 3, and 4. [4.3, 9.3, 19.3 to 19.6, 22.3, 25.6, 27.3, 28.2, 28.3, Table 19-4, Boxes CC-KR and CC-WE]

Many key risks constitute particular challenges for the least developed countries and vulnerable communities, given their limited ability to cope.

Increasing magnitudes of warming increase the likelihood of severe, pervasive, and irreversible impacts. Some risks of climate change are considerable at 1°C or 2°C above preindustrial levels (as shown in Box TS.5). Global climate change risks are high to very high with global mean temperature increase of 4°C or more above preindustrial levels in all reasons for concern (Box TS.5), and include severe and widespread impacts on unique and threatened systems, substantial species extinction, large risks to global and regional food security, and the combination of high temperature and humidity compromising normal human activities, including growing food or working outdoors in some areas for parts of the year (*high confidence*). See Box TS.6. The precise levels of climate change sufficient to trigger tipping points (thresholds for abrupt and irreversible change) remain uncertain, but the risk associated with crossing multiple tipping points in the earth system or in interlinked human and natural systems increases with rising temperature (*medium confidence*). [4.2, 4.3, 11.8, 19.5, 19.7, 26.5, Box CC-HS]

The overall risks of climate change impacts can be reduced by limiting the rate and magnitude of climate change. Risks are reduced substantially under the assessed scenario with the lowest temperature projections (RCP2.6 – low emissions) compared to the highest temperature projections (RCP8.5 – high emissions), particularly in the second half of the 21st century (*very high confidence*). Examples include reduced risk of negative agricultural yield impacts; of water scarcity; of major challenges to urban settlements and infrastructure from sea level rise; and of adverse impacts from heat extremes, floods, and droughts in areas where increased occurrence of these extremes is projected. Reducing climate change can also reduce the scale of adaptation that might be required. Under all assessed scenarios for adaptation and mitigation, some risk from adverse impacts remains (*very high confidence*). Because mitigation reduces the rate as well as the magnitude of warming, it also increases the time available for adaptation to a particular level of climate change, potentially by several decades, but adaptation cannot generally overcome all climate change effects. In addition to biophysical limits to adaptation for example under high temperatures, some adaptation options will be too costly or resource intensive or will be cost ineffective until climate change effects grow to merit investment costs (*high confidence*). Some mitigation or adaptation options also pose risks. [3.4, 3.5, 4.2, 4.4, 16.3, 16.6, 17.2, 19.7, 20.3, 22.4, 22.5, 25.10, Tables 3-2, 8-3, and 8-6, Boxes 16-3 and 25-1]

B-2. Sectoral Risks and Potential for Adaptation

For the near-term era of committed climate change (the next few decades) and the longer-term era of climate options (the second half

Box TS.6 | Consequences of Large Temperature Increase

This box provides a selection of salient climate change impacts projected for large temperature rise. Warming levels described here (e.g., 4°C warming) refer to global mean temperature increase above preindustrial levels, unless otherwise indicated.

With 4°C warming, climate change is projected to become an increasingly important driver of impacts on ecosystems, becoming comparable with land-use change. [4.2, 19.5] A number of studies project large increases in water stress, groundwater supplies, and drought in a number of regions with greater than 4°C warming, and decreases in others, generally placing already arid regions at greater water stress. [19.5]

Risks of large-scale singular events such as ice sheet disintegration, methane release from clathrates, and onset of long-term droughts in areas such as southwest North America [19.6, Box 26-1; WGI AR5 12.4, 12.5, 13.4], as well as regime shifts in ecosystems and substantial species loss [4.3, 19.6], are higher with increased warming. Sustained warming greater than some threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of up to 7 m (*high confidence*); current estimates indicate that the threshold is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) global mean warming. [WGI AR5 SPM, 5.8, 13.4, 13.5] Abrupt and irreversible ice loss from a potential instability of marine-based areas of the Antarctic ice sheet in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment. [19.6; WGI AR5 SPM, 5.8, 13.4, 13.5] Sea level rise of 0.45 to 0.82 m (mean 0.63 m) is *likely* by 2081–2100 under RCP8.5 (*medium confidence*) [WGI AR5 Tables SPM.2 and 13.5], with sea level continuing to rise beyond 2100.

The Atlantic Meridional Overturning Circulation (AMOC) will *very likely* weaken over the 21st century, with a best estimate of 34% loss (range 12 to 54%) under RCP8.5. [WGI AR5 SPM, 12.4] The release of carbon dioxide (CO_2) or methane (CH_4) to the atmosphere from thawing permafrost carbon stocks over the 21st century is assessed to be in the range of 50 to 250 GtC for Representative Concentration Pathway 8.5 (RCP8.5) (*low confidence*). [WGI AR5 SPM, 6.4] A nearly ice-free Arctic Ocean in September before mid-century is *likely* under RCP8.5 (*medium confidence*). [WGI AR5 SPM, 11.3, 12.4, 12.5]

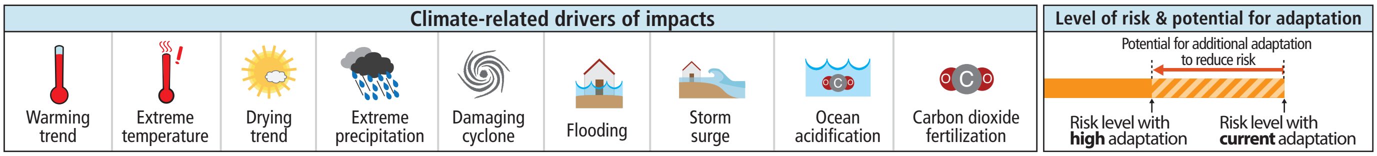
By 2100 for the high-emission scenario RCP8.5, the combination of high temperature and humidity in some areas for parts of the year is projected to compromise normal human activities, including growing food or working outdoors (*high confidence*). [11.8] Global temperature increases of ~4°C or more above late-20th-century levels, combined with increasing food demand, would pose large risks to food security globally and regionally (*high confidence*). [7.4, 7.5, Table 7-3, Figures 7-1, 7-4, and 7-7, Box 7-1]

Under 4°C warming, some models project large increases in fire risk in parts of the world. [4.3, Figure 4-6] 4°C warming implies a substantial increase in extinction risk for terrestrial and freshwater species, although there is *low agreement* concerning the fraction of species at risk. [4.3] Widespread coral reef mortality is expected with significant impacts on coral reef ecosystems (*high confidence*). [5.4, Box CC-CR] Assessments of potential ecological impacts at and above 4°C warming imply a high risk of extensive loss of biodiversity with concomitant loss of ecosystem services (*high confidence*). [4.3, 19.3, 19.5, Box 25-6]

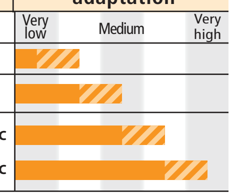
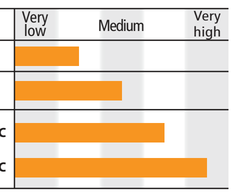
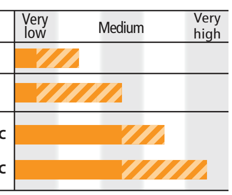
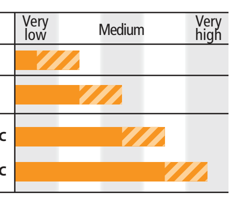
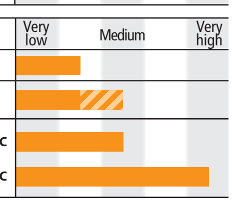
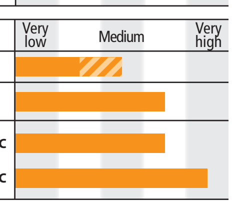
Projected large increases in exposure to water stress, fluvial and coastal flooding, negative impacts on crop yields, and disruption of ecosystem function and services would represent large, potentially compounding impacts of climate change on society generally and on the global economy. [19.4 to 19.6]

of the 21st century and beyond), climate change will amplify existing climate-related risks and create new risks for natural and human systems, dependent on the magnitude and rate of climate change and on the vulnerability and exposure of interlinked human and natural systems. Some of these risks will be limited to a particular sector or region, and others will have cascading effects. To a lesser extent, climate change will also have some potential benefits. A selection of key sectoral risks identified with *medium* to *high confidence* is presented in Table TS.4.

Table TS.4 | Key sectoral risks from climate change and the potential for reducing risks through adaptation and mitigation. Key risks have been identified based on assessment of the relevant scientific, technical, and socioeconomic literature detailed in supporting chapter sections. Identification of key risks was based on expert judgment using the following specific criteria: large magnitude, high probability, or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation. Each key risk is characterized as very low to very high for three timeframes: the present, near term (here, assessed over 2030–2040), and longer term (here, assessed over 2080–2100). The risk levels integrate probability and consequence over the widest possible range of potential outcomes, based on available literature. These potential outcomes result from the interaction of climate-related hazards, vulnerability, and exposure. Each risk level reflects total risk from climatic and non-climatic factors. For the near-term era of committed climate change, projected levels of global mean temperature increase do not diverge substantially for different emission scenarios. For the longer-term era of climate options, risk levels are presented for two scenarios of global mean temperature increase (2°C and 4°C above preindustrial levels). These scenarios illustrate the potential for mitigation and adaptation to reduce the risks related to climate change. For the present, risk levels were estimated for current adaptation and a hypothetical highly adapted state, identifying where current adaptation deficits exist. For the two future timeframes, risk levels were estimated for a continuation of current adaptation and for a highly adapted state, representing the potential for and limits to adaptation. Climate-related drivers of impacts are indicated by icons. Risk levels are not necessarily comparable because the assessment considers potential impacts and adaptation in different physical, biological, and human systems across diverse contexts. This assessment of risks acknowledges the importance of differences in values and objectives in interpretation of the assessed risk levels.

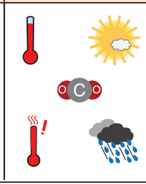
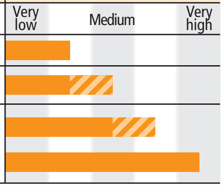
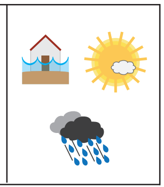
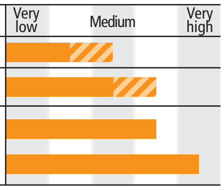
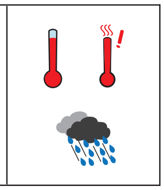
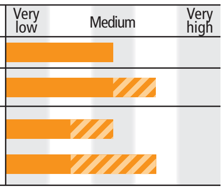
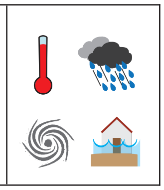
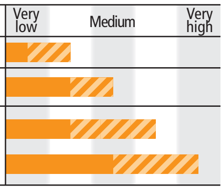
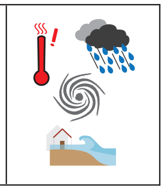
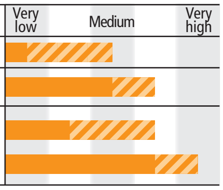
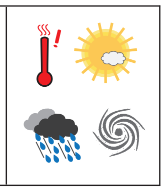
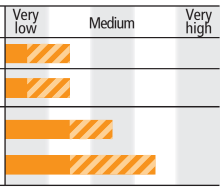
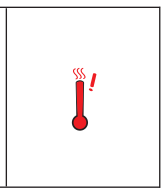
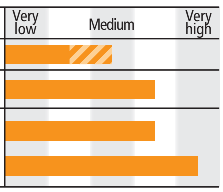
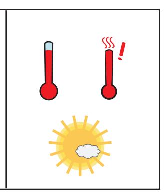
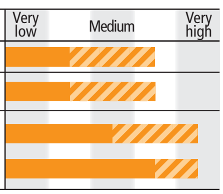


Global Risks

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Reduction in terrestrial carbon sink: Carbon stored in terrestrial ecosystems is vulnerable to loss back into the atmosphere, resulting from increased fire frequency due to climate change and the sensitivity of ecosystem respiration to rising temperatures (*medium confidence*) [4.2, 4.3]	• Adaptation options include managing land use (including deforestation), fire and other disturbances, and non-climatic stressors.	Warming trend, Extreme temperature, Drying trend	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Boreal tipping point: Arctic ecosystems are vulnerable to abrupt change related to the thawing of permafrost, spread of shrubs in tundra, and increase in pests and fires in boreal forests (*medium confidence*) [4.3, Box 4-4]	• There are few adaptation options in the Arctic.	Warming trend, Extreme temperature	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Amazon tipping point: Moist Amazon forests could change abruptly to less-carbon-dense, drought- and fire-adapted ecosystems (*low confidence*) [4.3, Box 4-3]	• Policy and market measures can reduce deforestation and fire.	Warming trend, Extreme temperature, Drying trend	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Increased risk of species extinction: A large fraction of the species assessed is vulnerable to extinction due to climate change, often in interaction with other threats. Species with an intrinsically low dispersal rate, especially when occupying flat landscapes where the projected climate velocity is high, and species in isolated habitats such as mountaintops, islands, or small protected areas are especially at risk. Cascading effects through organism interactions, especially those vulnerable to phenological changes, amplify risk (*high confidence*) [4.3, 4.4]	• Adaptation options include reduction of habitat modification and fragmentation, pollution, over-exploitation, and invasive species; protected area expansion; assisted dispersal; and *ex situ* conservation.	Warming trend, Extreme temperature, Drying trend	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Reduced growth and survival of commercially valuable shellfish and other calcifiers (e.g., reef-building corals, calcareous red algae) due to ocean acidification (*high confidence*) [5.3, 6.1, 6.3, 6.4, 30.3, Box CC-OA]	• Evidence for differential resistance and evolutionary adaptation of some species exists, but they are *likely* to be limited at higher CO_2 concentrations and temperatures. • Adaptation options include exploiting more resilient species or protecting habitats with low natural CO_2 levels, as well as reducing other stresses, mainly pollution, and limiting pressures from tourism and fishing.	Ocean acidification	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Marine biodiversity loss with high rate of climate change (*medium confidence*) [6.3, 6.4, Table 30-4, Box CC-MB]	• Adaptation options are limited to reducing other stresses, mainly pollution, and limiting pressures from coastal human activities such as tourism and fishing.	Warming trend, Extreme temperature, Ocean acidification	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	

Continued next page →

Table TS.4 (continued)

Global Risks				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Negative impacts on average crop yields and increases in yield variability due to climate change (*high confidence*) [7.2 to 7.5, Figure 7-5, Box 7-1]	• Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of projections for the period 2030–2049 showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared to the late 20th century. After 2050 the risk of more severe yield impacts increases and depends on the level of warming.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Urban risks associated with water supply systems (*high confidence*) [8.2, 8.3]	• Adaptation options include changes to network infrastructure as well as demand-side management to ensure sufficient water supplies and quality, increased capacities to manage reduced freshwater availability, and flood risk reduction.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Urban risks associated with energy systems (*high confidence*) [8.2, 8.4]	• Most urban centers are energy intensive, with energy-related climate policies focused only on mitigation measures. A few cities have adaptation initiatives underway for critical energy systems. There is potential for non-adapted, centralized energy systems to magnify impacts, leading to national and transboundary consequences from localized extreme events.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Urban risks associated with housing (*high confidence*) [8.3]	• Poor quality, inappropriately located housing is often most vulnerable to extreme events. Adaptation options include enforcement of building regulations and upgrading. Some city studies show the potential to adapt housing and promote mitigation, adaptation, and development goals simultaneously. Rapidly growing cities, or those rebuilding after a disaster, especially have opportunities to increase resilience, but this is rarely realized. Without adaptation, risks of economic losses from extreme events are substantial in cities with high-value infrastructure and housing assets, with broader economic effects possible.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Displacement associated with extreme events (*high confidence*) [12.4]	• Adaptation to extreme events is well understood, but poorly implemented even under present climate conditions. Displacement and involuntary migration are often temporary. With increasing climate risks, displacement is more likely to involve permanent migration.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Violent conflict arising from deterioration in resource-dependent livelihoods such as agriculture and pastoralism (*high confidence*) [12.5]	Adaptation options: • Buffering rural incomes against climate shocks, for example through livelihood diversification, income transfers, and social safety net provision • Early warning mechanisms to promote effective risk reduction • Well-established strategies for managing violent conflict that are effective but require significant resources, investment, and political will		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Declining work productivity, increasing morbidity (e.g., dehydration, heat stroke, and heat exhaustion), and mortality from exposure to heat waves. Particularly at risk are agricultural and construction workers as well as children, homeless people, the elderly, and women who have to walk long hours to collect water (*high confidence*) [13.2, Box 13-1]	• Adaptation options are limited for people who are dependent on agriculture and cannot afford agricultural machinery. • Adaptation options are limited in the construction sector where many poor people work under insecure arrangements. • Adaptation limits may be exceeded in certain areas in a +4°C world.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Reduced access to water for rural and urban poor people due to water scarcity and increasing competition for water (*high confidence*) [13.2, Box 13-1]	• Adaptation through reducing water use is not an option for the many people already lacking adequate access to safe water. Access to water is subject to various forms of discrimination, for instance due to gender and location. Poor and marginalized water users are unable to compete with water extraction by industries, large-scale agriculture, and other powerful users.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	

For extended summary of sectoral risks and the more limited potential benefits, see introductory overviews for each sector below and also Chapters 3 to 13.

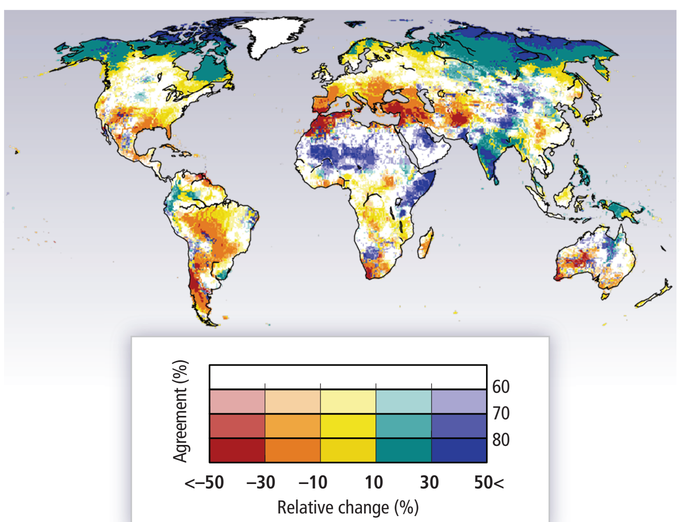
Freshwater Resources

Freshwater-related risks of climate change increase significantly with increasing greenhouse gas concentrations (*robust evidence*, *high agreement*). The fraction of global population experiencing water scarcity and the fraction affected by major river floods increase with the level of warming in the 21st century. See, for example, Figure TS.6. [3.4, 3.5, 26.3, Table 3-2, Box 25-8]

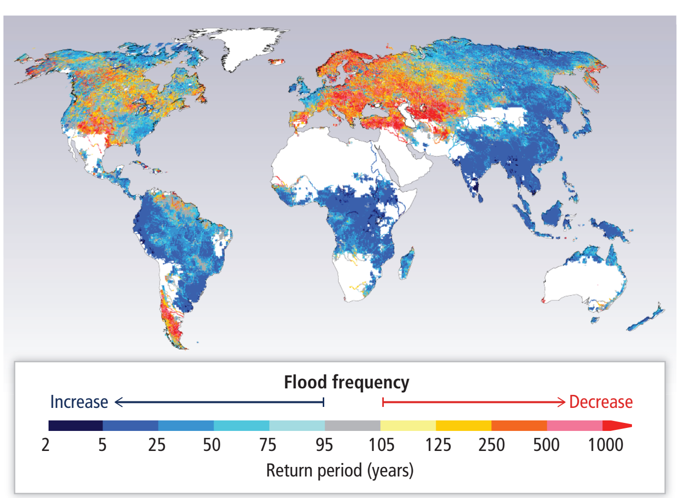
Climate change over the 21st century is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions (*robust evidence*, *high agreement*), intensifying competition for water among sectors (*limited evidence*, *medium agreement*). In presently dry regions, drought frequency will *likely* increase by the end of the 21st century under RCP8.5 (*medium confidence*). In contrast, water resources are projected to increase at high latitudes (*robust evidence*, *high agreement*). Climate change is projected to reduce raw water quality and pose risks to drinking water quality even with conventional treatment, due to interacting factors: increased temperature; increased sediment, nutrient, and pollutant loadings from heavy rainfall; increased concentration of pollutants during droughts; and disruption of treatment facilities during floods (*medium evidence*, *high agreement*). [3.2, 3.4, 3.5, 22.3, 23.9, 25.5, 26.3, Tables 3-2 and 23-3, Boxes CC-RF and CC-WE; WGI AR5 12.4]

Adaptive water management techniques, including scenario planning, learning-based approaches, and flexible and low-regret solutions, can help create resilience to uncertain hydrological changes and impacts due to climate change (*limited evidence*, *high agreement*). Barriers to progress include lack of human and institutional capacity, financial resources, awareness, and communication. [3.6, Box 25-2]

(A)



(B)



(C)

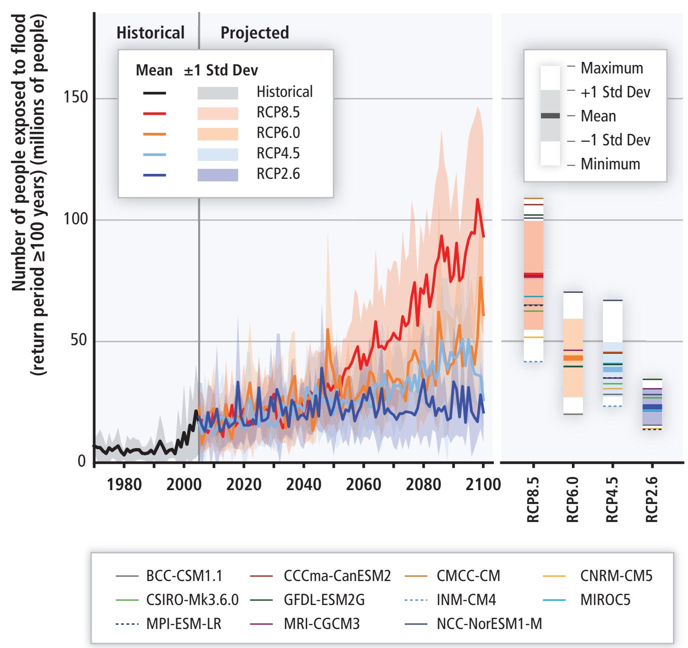


Figure TS.6 | (A) Percentage change of mean annual streamflow for a global mean temperature rise of 2°C above 1980–2010. Color hues show the multi-model mean change across 5 General Circulation Models (GCMs) and 11 Global Hydrological Models (GHMs), and saturation shows the agreement on the sign of change across all 55 GHM–GCM combinations (percentage of model runs agreeing on the sign of change). (B and C) Projected change in river flood return period and exposure, based on one hydrological model driven by 11 GCMs and on global population in 2005. (B) In the 2080s under RCP8.5, multi-model median return period (years) for the 20th-century 100-year flood. (C) Global exposure to the 20th-century 100-year flood in millions of people. Left: Ensemble means of historical (black line) and future simulations (colored lines) for each scenario. Shading denotes ±1 standard deviation. Right: Maximum and minimum (extent of white), mean (thick colored lines), ±1 standard deviation (extent of shading), and projections of each GCM (thin colored lines) averaged over the 21st century. [Figures 3-4 and 3-6]

Terrestrial and Freshwater Ecosystems

Climate change is projected to be a powerful stressor on terrestrial and freshwater ecosystems in the second half of the 21st century, especially under high-warming scenarios such as RCP6.0 and 8.5 (*high confidence*). Through to 2040 globally, direct human impacts such as land-use change, pollution, and water resource development will continue to dominate threats to most freshwater ecosystems (*high confidence*) and most terrestrial ecosystems (*medium confidence*). Many species will be unable to track suitable climates under mid- and high-range rates of climate change (i.e., RCP4.5, 6.0, and 8.5) during the 21st century (*medium confidence*). Lower rates of change (i.e., RCP2.6) will pose fewer problems. See Figure TS.7. Some species will adapt to new climates. Those that cannot adapt sufficiently fast will decrease in abundance or go extinct in part or all of their ranges. Increased tree mortality and associated forest dieback is projected to occur in many regions over the 21st century, due to increased temperatures and drought (*medium confidence*). Forest dieback poses risks for carbon storage, biodiversity, wood production, water quality, amenity, and economic activity. Management actions, such as maintenance of genetic diversity, assisted species migration and dispersal, manipulation of disturbance regimes (e.g., fires, floods), and reduction of other stressors, can reduce, but not eliminate, risks of impacts to terrestrial and freshwater ecosystems due to climate change, as well as increase the inherent capacity of ecosystems and their species to adapt to a changing climate (*high confidence*). [4.3, 4.4, 25.6, 26.4, Boxes 4-2, 4-3, and CC-RF]

A large fraction of both terrestrial and freshwater species faces increased extinction risk under projected climate change during and beyond the 21st century, especially as climate change interacts with other stressors, such as habitat modification, over-exploitation, pollution, and invasive species (*high confidence*). Extinction risk is increased under all RCP scenarios, with risk increasing with both magnitude and rate of climate change. Models project that the risk of species extinctions will increase in the future due to climate change, but there is *low agreement* concerning the fraction of species at increased risk, the regional and taxonomic distribution of such extinctions, and the timeframe over which extinctions could occur. Some aspects leading to uncertainty in the quantitative projections of extinction risks were not taken into account in previous models; as more realistic details are included, it has been shown that the extinction risks may be either under- or overestimated when based on simpler models. [4.3, 25.6]

Within this century, magnitudes and rates of climate change associated with medium- to high-emission scenarios (RCP4.5, 6.0, and 8.5) pose high risk of abrupt and irreversible regional-scale change in the composition, structure, and function of

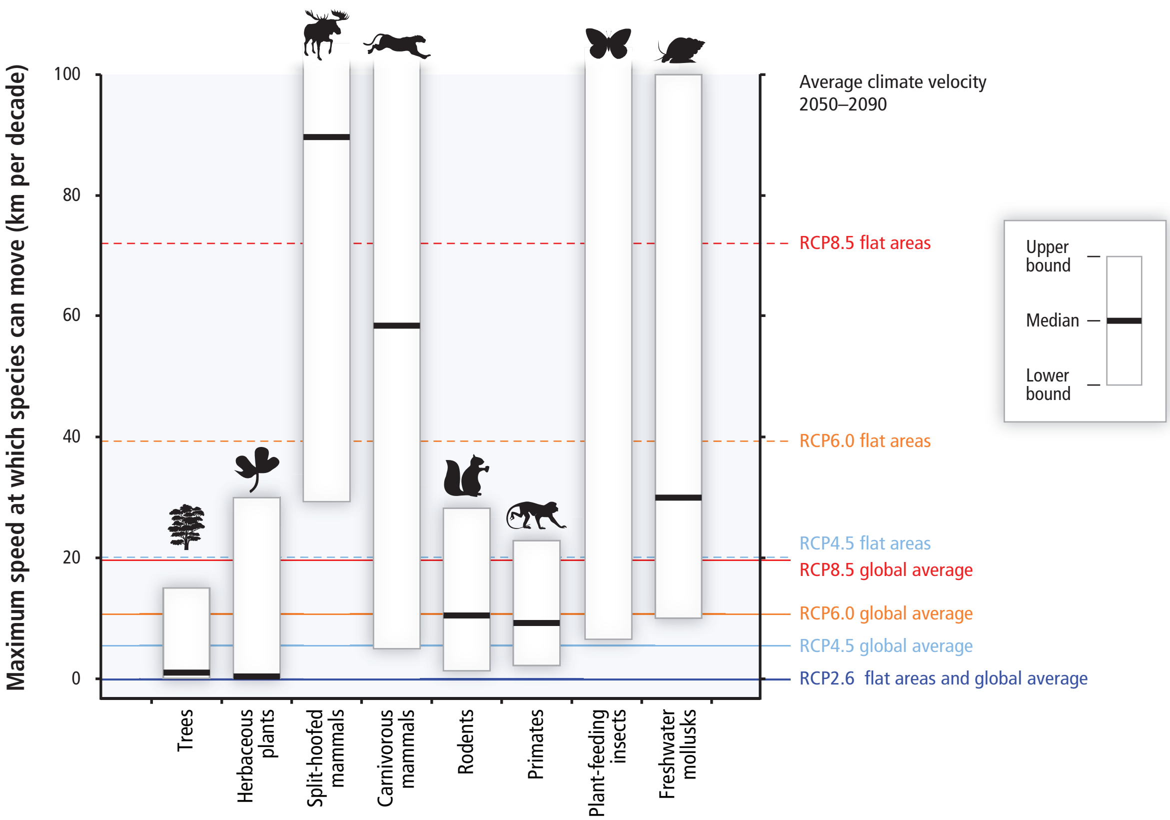


Figure TS.7 | Maximum speeds at which species can move across landscapes (based on observations and models; vertical axis on left), compared with speeds at which temperatures are projected to move across landscapes (climate velocities for temperature; vertical axis on right). Human interventions, such as transport or habitat fragmentation, can greatly increase or decrease speeds of movement. White boxes with black bars indicate ranges and medians of maximum movement speeds for trees, plants, mammals, plant-feeding insects (median not estimated), and freshwater mollusks. For RCP2.6, 4.5, 6.0, and 8.5 for 2050–2090, horizontal lines show climate velocity for the global-land-area average and for large flat regions. Species with maximum speeds below each line are expected to be unable to track warming in the absence of human intervention. [Figure 4-5]

terrestrial and freshwater ecosystems, including wetlands (*medium confidence*). Examples that could lead to substantial impact on climate are the boreal–tundra Arctic system (*medium confidence*) and the Amazon forest (*low confidence*). For the boreal–tundra system, continued climate change will transform the species composition, land cover, drainage, and permafrost extent of the boreal–tundra system, leading to decreased albedo and the release of greenhouse gases (*medium confidence*), with adaptation measures unable to prevent substantial change (*high confidence*). Increased severe drought together with land-use change and forest fire would cause much of the Amazon forest to transform to less-dense drought- and fire-adapted ecosystems, increasing risk for biodiversity while decreasing net carbon uptake from the atmosphere (*low confidence*). Large reductions in deforestation, as well as wider application of effective wildfire management, will lower the risk of abrupt change in the Amazon, as well as potential negative impacts of that change (*medium confidence*). [4.2, 4.3, Figure 4-8, Boxes 4-3 and 4-4]

The natural carbon sink provided by terrestrial ecosystems is partially offset at the decadal timescale by carbon released through the conversion of natural ecosystems (principally forests) to farm and grazing land and through ecosystem degradation (*high confidence*). Carbon stored in the terrestrial biosphere (e.g., in peatlands, permafrost, and forests) is susceptible to loss to the atmosphere as a result of climate change, deforestation, and ecosystem degradation. [4.2, 4.3, Box 4-3]

Coastal Systems and Low-lying Areas

Due to sea level rise projected throughout the 21st century and beyond, coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion (*very high confidence*). The population and assets projected to be exposed to coastal risks as well as human pressures on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, and urbanization (*high confidence*). The relative costs of coastal adaptation vary strongly among and within regions and countries for the 21st century. Some low-lying developing countries and small island states are expected to face very high impacts that, in some cases, could have associated damage and adaptation costs of several percentage points of GDP. [5.3 to 5.5, 8.2, 22.3, 24.4, 25.6, 26.3, 26.8, Table 26-1, Box 25-1]

Marine Systems

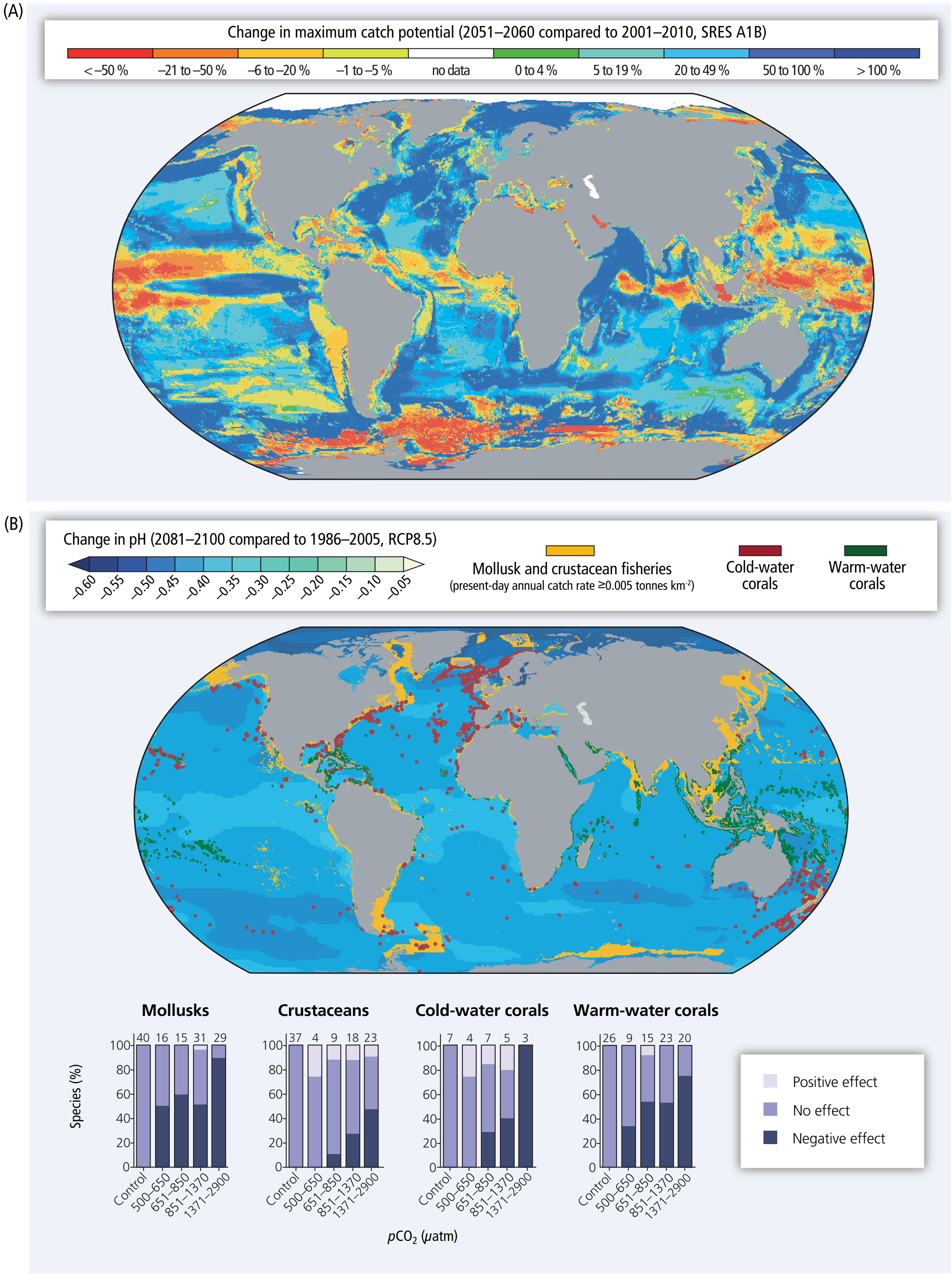
By mid 21st century, spatial shifts of marine species will cause species richness and fisheries catch potential to increase, on average, at mid and high latitudes (*high confidence*) and to decrease at tropical latitudes (*medium confidence*), resulting in global redistribution of catch potential for fishes and invertebrates, with implications for food security (*medium confidence*). Spatial shifts of marine species due to projected warming will cause high-latitude invasions and high local-extinction rates in the tropics and semi-enclosed seas (*medium confidence*). Animal displacements will cause a 30 to 70% increase in the fisheries yield of some high-latitude regions by 2055 (relative to 2005), a redistribution at mid latitudes, and a drop of 40 to 60% in some of the tropics and the Antarctic, for 2°C warming above preindustrial levels (*medium confidence* for direction of fisheries' yield trends, *low confidence* for the precise magnitudes of yield change). See Figure TS.8A. The progressive expansion of oxygen minimum zones and anoxic "dead zones" is projected to further constrain the habitat of fishes and other O_2-dependent organisms (*medium confidence*). Open-ocean net primary production is projected to redistribute and, by 2100, fall globally under all RCP scenarios. [6.3 to 6.5, 7.4, 25.6, 28.3, 30.4 to 30.6, Boxes CC-MB and CC-PP]

Due to projected climate change by the mid 21st century and beyond, global marine-species redistribution and marine-biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem goods and services (*high confidence*). Socioeconomic vulnerability is highest in developing tropical countries, leading to risks from reduced supplies, income, and employment from marine fisheries. [6.4, 6.5]

For medium- to high-emission scenarios (RCP4.5, 6.0, and 8.5), ocean acidification poses substantial risks to marine ecosystems, especially polar ecosystems and coral reefs, associated with impacts on the physiology, behavior, and population dynamics of individual species from phytoplankton to animals (*medium* to *high confidence*). See Box TS.7. Highly calcified mollusks, echinoderms, and reef-building corals are more sensitive than crustaceans (*high confidence*) and fishes (*low confidence*), with potentially detrimental consequences for fisheries and livelihoods (Figure TS.8B). Ocean acidification acts together with other global changes (e.g., warming, decreasing oxygen levels) and with local changes (e.g., pollution, eutrophication) (*high confidence*). Simultaneous drivers, such as warming and ocean acidification, can lead to interactive, complex, and amplified impacts for species and ecosystems. [5.4, 6.3 to 6.5, 22.3, 25.6, 28.3, 30.5, Boxes CC-CR and CC-OA]

Climate change adds to the threats of over-fishing and other non-climatic stressors, thus complicating marine management regimes (*high confidence*). In the short term, strategies including climate forecasting and early warning systems can reduce risks from ocean warming and acidification for some fisheries and aquaculture industries. Fisheries and aquaculture industries with high-technology

Figure TS.8 | Climate change risks for fisheries. (A) Projected global redistribution of maximum catch potential of ~1000 exploited fish and invertebrate species. Projections compare the 10-year averages 2001–2010 and 2051–2060 using SRES A1B, without analysis of potential impacts of overfishing or ocean acidification. (B) Marine mollusk and crustacean fisheries (present-day estimated annual catch rates ≥0.005 tonnes km^{-2}) and known locations of cold- and warm-water corals, depicted on a global map showing the projected distribution of ocean acidification under RCP8.5 (pH change from 1986–2005 to 2081–2100). [WGI AR5 Figure SPM.8] The bottom panel compares sensitivity to ocean acidification across mollusks, crustaceans, and corals, vulnerable animal phyla with socioeconomic relevance (e.g., for coastal protection and fisheries). The number of species analyzed across studies is given for each category of elevated CO_2. For 2100, RCP scenarios falling within each CO_2 partial pressure (pCO_2) category are as follows: RCP4.5 for 500–650 μatm (approximately equivalent to ppm in the atmosphere), RCP6.0 for 651–850 μatm, and RCP8.5 for 851–1370 μatm. By 2150, RCP8.5 falls within the 1371–2900 μatm category. The control category corresponds to 380 μatm. [6.1, 6.3, 30.5, Figures 6-10 and 6-14; WGI AR5 Box SPM.1]


(A)
Change in maximum catch potential (2051–2060 compared to 2001–2010, SRES A1B)
< –50 %
–21 to –50 %
–6 to –20 %
–1 to –5 %
no data
0 to 4 %
5 to 19 %
20 to 49 %
50 to 100 %
> 100 %
(B)
Change in pH (2081–2100 compared to 1986–2005, RCP8.5)
–0.60
–0.55
–0.50
–0.45
–0.40
–0.35
–0.30
–0.25
–0.20
–0.15
–0.10
–0.05
Mollusk and crustacean fisheries
(present-day annual catch rate ≥0.005 tonnes km-2)
Cold-water corals
Warm-water corals
Mollusks
Crustaceans
Cold-water corals
Warm-water corals
Species (%)
100
80
60
40
20
0
40 16 15 31 29
37 4 9 18 23
7 4 7 5 3
26 9 15 23 20
Control
500–650
651–850
851–1370
1371–2900
pCO2 (µatm)
Positive effect
No effect
Negative effect

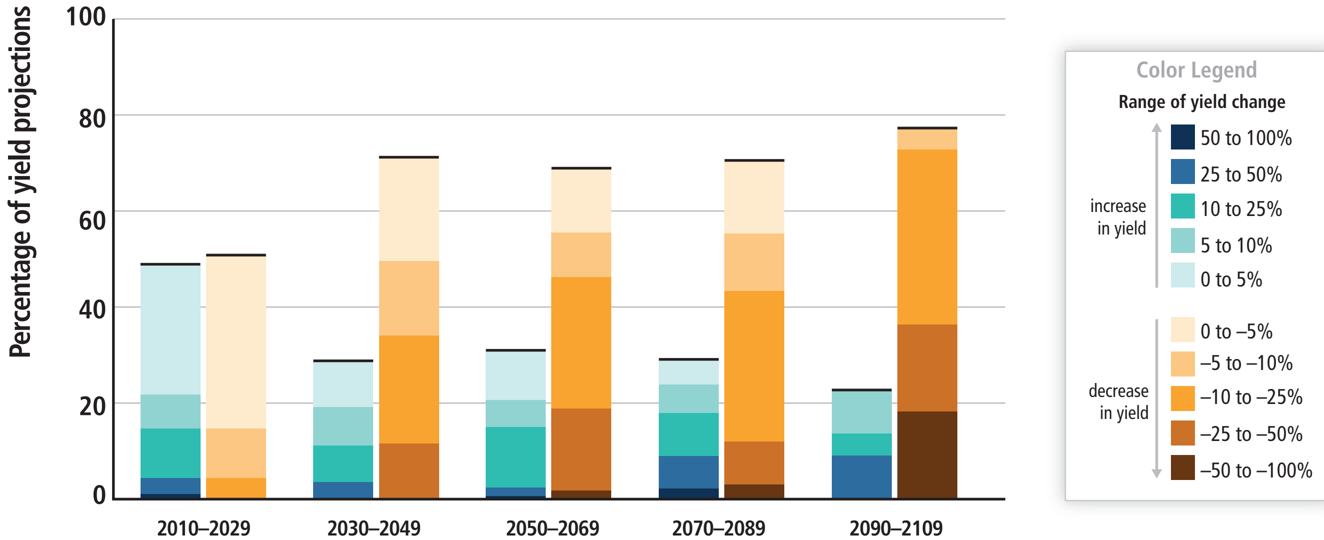


Figure TS.9 | Summary of projected changes in crop yields, due to climate change over the 21st century. The figure includes projections for different emission scenarios, for tropical and temperate regions, and for adaptation and no-adaptation cases combined. Relatively few studies have considered impacts on cropping systems for scenarios where global mean temperatures increase by 4°C or more. For five timeframes in the near term and long term, data (n=1090) are plotted in the 20-year period on the horizontal axis that includes the midpoint of each future projection period. Changes in crop yields are relative to late-20th-century levels. Data for each timeframe sum to 100%. [Figure 7-5]

and/or large investments, as well as marine shipping and oil and gas industries, have high capacities for adaptation due to greater development of environmental monitoring, modeling, and resource assessments. For smaller-scale fisheries and developing countries, building social resilience, alternative livelihoods, and occupational flexibility represent important strategies for reducing the vulnerability of ocean-dependent human communities. [6.4, 7.3, 7.4, 25.6, 29.4, 30.6, 30.7]

Food Security and Food Production Systems

For the major crops (wheat, rice, and maize) in tropical and temperate regions, climate change without adaptation is projected to negatively impact aggregate production for local temperature increases of 2°C or more above late-20th-century levels, although individual locations may benefit (*medium confidence*). Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of projections for the period 2030–2049 showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared to the late 20th century. After 2050 the risk of more severe yield impacts increases and depends on the level of warming. See Figure TS.9. Climate change is projected to progressively increase inter-annual variability of crop yields in many regions. These projected impacts will occur in the context of rapidly rising crop demand. [7.4, 7.5, 22.3, 24.4, 25.7, 26.5, Table 7-2, Figures 7-4, 7-5, 7-6, 7-7, and 7-8]

All aspects of food security are potentially affected by climate change, including food access, utilization, and price stability (*high confidence*). Redistribution of marine fisheries catch potential towards higher latitudes poses risk of reduced supplies, income, and employment in tropical countries, with potential implications for food security (*medium confidence*). Global temperature increases of ~4°C or more above late-20th-century levels, combined with increasing food demand, would pose large risks to food security globally and regionally (*high confidence*). Risks to food security are generally greater in low-latitude areas. [6.3 to 6.5, 7.4, 7.5, 9.3, 22.3, 24.4, 25.7, 26.5, Table 7-3, Figures 7-1, 7-4, and 7-7, Box 7-1]

Urban Areas

Many global risks of climate change are concentrated in urban areas (*medium confidence*). Steps that build resilience and enable sustainable development can accelerate successful climate-change adaptation globally. Heat stress, extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, and water scarcity pose risks in urban areas for people, assets, economies, and ecosystems (*very high confidence*). Risks are amplified for those lacking essential infrastructure and services or living in poor-quality housing and exposed areas. Reducing basic service deficits, improving housing, and building resilient infrastructure systems could significantly reduce vulnerability and exposure in urban areas. Urban adaptation benefits from effective multi-level urban risk governance, alignment of policies and incentives, strengthened local government and community adaptation capacity, synergies with the private sector, and appropriate financing and institutional development (*medium confidence*). Increased capacity, voice, and influence of low-income groups and vulnerable communities and their partnerships with local governments also benefit adaptation. [3.5, 8.2 to 8.4, 22.3, 24.4, 24.5, 26.8, Table 8-2, Boxes 25-9 and CC-HS]

Rural Areas

Major future rural impacts are expected in the near term and beyond through impacts on water availability and supply, food security, and agricultural incomes, including shifts in production areas of food and non-food crops across the world (*high

***confidence*).** These impacts are expected to disproportionately affect the welfare of the poor in rural areas, such as female-headed households and those with limited access to land, modern agricultural inputs, infrastructure, and education. Climate change will increase international agricultural trade volumes in both physical and value terms (*limited evidence*, *medium agreement*). Importing food can help countries adjust to climate change-induced domestic productivity shocks while short-term food deficits in developing countries with low income may have to be met through food aid. Further adaptations for agriculture, water, forestry, and biodiversity can occur through policies taking account of rural decision-making contexts. Trade reform and investment can improve market access for small-scale farms (*medium confidence*). Valuation of non-marketed ecosystem services and limitations of economic valuation models that aggregate across contexts pose challenges for valuing rural impacts. [9.3, 25.9, 26.8, 28.2, 28.4, Box 25-5]

Key Economic Sectors and Services

For most economic sectors, the impacts of drivers such as changes in population, age structure, income, technology, relative prices, lifestyle, regulation, and governance are projected to be large relative to the impacts of climate change (*medium evidence*, *high agreement*). Climate change is projected to reduce energy demand for heating and increase energy demand for cooling in the residential and commercial sectors (*robust evidence*, *high agreement*). Climate change is projected to affect energy sources and technologies differently, depending on resources (e.g., water flow, wind, insolation), technological processes (e.g., cooling), or locations (e.g., coastal regions, floodplains) involved. More severe and/or frequent extreme weather events and/or hazard types are projected to increase losses and loss variability in various regions and challenge insurance systems to offer affordable coverage while raising more risk-based capital, particularly in developing countries. Large-scale public-private risk reduction initiatives and economic diversification are examples of adaptation actions. [3.5, 10.2, 10.7, 10.10, 17.4, 17.5, 25.7, 26.7 to 26.9, Box 25-7]

Climate change may influence the integrity and reliability of pipelines and electricity grids (*medium evidence*, *medium agreement*). Climate change may require changes in design standards for the construction and operation of pipelines and of power transmission and distribution lines. Adopting existing technology from other geographical and climatic conditions may reduce the cost of adapting new infrastructure as well as the cost of retrofitting existing pipelines and grids. Climate change may negatively affect transport infrastructure (*limited evidence*, *high agreement*). All infrastructure is vulnerable to freeze-thaw cycles; paved roads are particularly vulnerable to temperature extremes, unpaved roads and bridges to precipitation extremes. Transport infrastructure on ice or permafrost is especially vulnerable. [10.2, 10.4, 25.7, 26.7]

Climate change will affect tourism resorts, particularly ski resorts, beach resorts, and nature resorts (*robust evidence*, *high agreement*), and tourists may spend their holidays at higher altitudes and latitudes (*medium evidence*, *high agreement*). The economic implications of climate-change-induced changes in tourism demand and supply entail gains for countries closer to the poles and countries with higher elevations and losses for other countries. [10.6, 25.7]

Global economic impacts from climate change are difficult to estimate. Economic impact estimates completed over the past 20 years vary in their coverage of subsets of economic sectors and depend on a large number of assumptions, many of which are disputable, and many estimates do not account for catastrophic changes, tipping points, and many other factors. With these recognized limitations, the incomplete estimates of global annual economic losses for additional temperature increases of ~2°C are between 0.2 and 2.0% of income (±1 standard deviation around the mean) (*medium evidence*, *medium agreement*). Losses are *more likely than not* to be greater, rather than smaller, than this range (*limited evidence*, *high agreement*). Additionally, there are large differences between and within countries. Losses accelerate with greater warming (*limited evidence*, *high agreement*), but few quantitative estimates have been completed for additional warming around 3°C or above. Estimates of the incremental economic impact of emitting carbon dioxide lie between a few dollars and several hundreds of dollars per tonne of carbon[3] (*robust evidence*, *medium agreement*). Estimates vary strongly with the assumed damage function and discount rate. [10.9]

Human Health

Until mid-century, projected climate change will impact human health mainly by exacerbating health problems that already exist (*very high confidence*). Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change (*high confidence*). Examples include greater likelihood of injury, disease, and death due to more intense heat waves and fires (*very high confidence*); increased likelihood of under-nutrition resulting from diminished food production in poor regions (*high confidence*); risks from lost work capacity and reduced labor productivity in vulnerable populations; and increased risks from food- and water-borne diseases (*very high confidence*) and vector-borne diseases (*medium confidence*). Impacts on health will be reduced, but not eliminated, in populations that benefit from rapid social and economic development, particularly among the poorest and least healthy groups (*high confidence*). Climate change will increase demands for health care services and facilities, including public health programs, disease prevention activities, health care personnel, infrastructure, and supplies for treatment (*medium evidence*, *high agreement*). Positive effects are expected to include modest reductions in cold-related mortality and morbidity in some areas due to fewer cold extremes (*low confidence*), geographical shifts in food production (*medium confidence*), and reduced capacity of vectors to transmit some diseases. But globally over the 21st century, the magnitude and severity of negative impacts are projected to increasingly outweigh positive impacts (*high confidence*). The most effective vulnerability reduction measures for health in the near term are programs that implement and improve basic public health measures such as provision of clean water and sanitation, secure essential health care including vaccination and child health services,

[3] 1 tonne of carbon = 3.667 tonne of CO_2

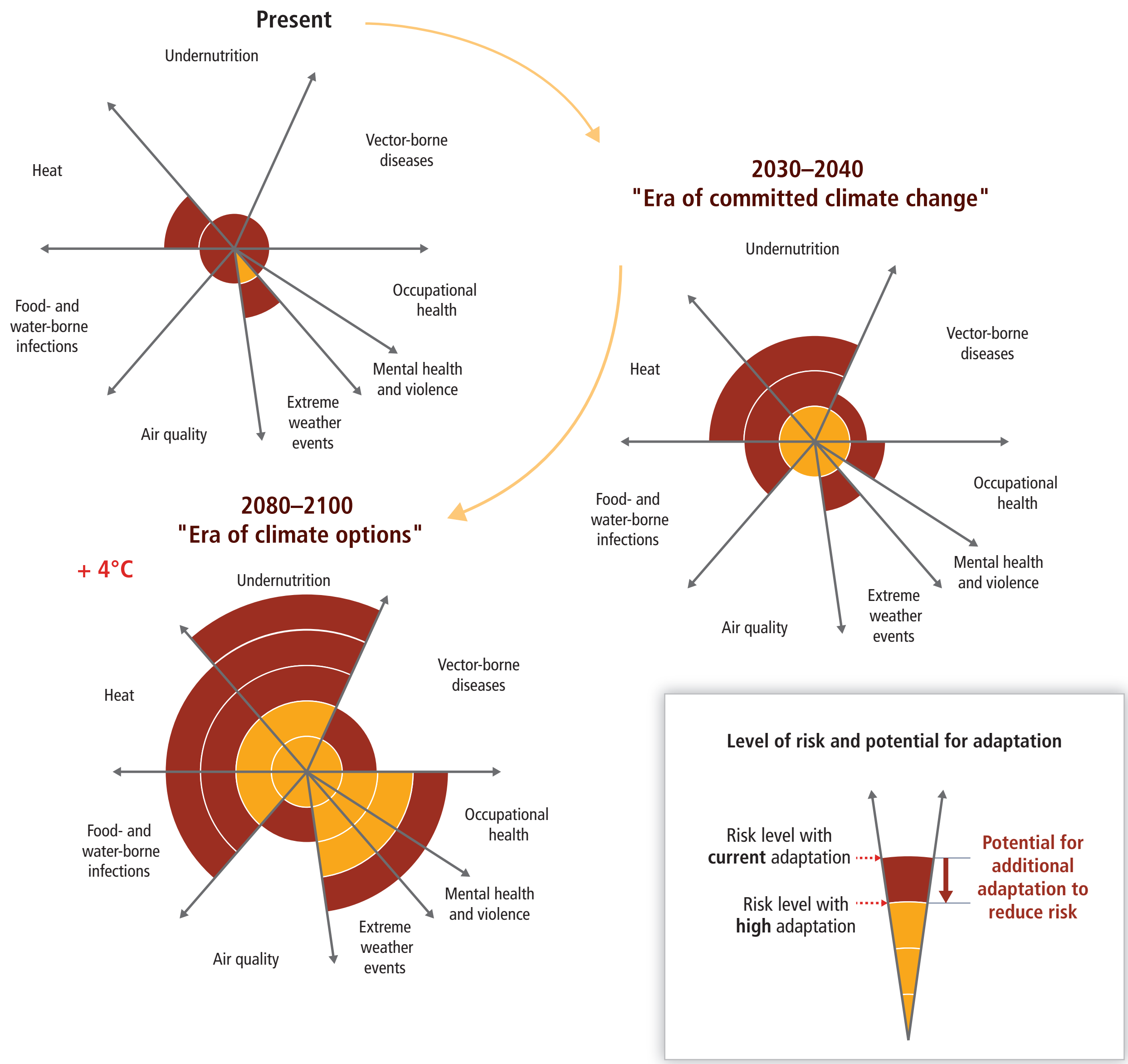


Figure TS.10 | Conceptual presentation of health risks from climate change and the potential for risk reduction through adaptation. Risks are identified in eight health-related categories based on assessment of the literature and expert judgments by authors of Chapter 11. The width of the slices indicates in a qualitative way relative importance in terms of burden of ill-health globally at present. Risk levels are assessed for the present and for the near-term era of committed climate change (here, for 2030–2040). For some categories, for example, vector-borne diseases, heat/cold stress, and agricultural production and undernutrition, there may be benefits to health in some areas, but the net impact is expected to be negative. Risk levels are also presented for the longer-term era of climate options (here, for 2080–2100) for global mean temperature increase of 4°C above preindustrial levels. For each timeframe, risk levels are estimated for the current state of adaptation and for a hypothetical highly adapted state, indicated by different colors. [Figure 11-6]

increase capacity for disaster preparedness and response, and alleviate poverty (*very high confidence*). By 2100 for the high-emission scenario RCP8.5, the combination of high temperature and humidity in some areas for parts of the year is projected to compromise normal human activities, including growing food or working outdoors (*high confidence*). See Figure TS.10. [8.2, 11.3 to 11.8, 19.3, 22.3, 25.8, 26.6, Figure 25-5, Box CC-HS]

Human Security

Human security will be progressively threatened as the climate changes (*robust evidence*, *high agreement*). Human insecurity almost never has single causes, but instead emerges from the interaction of multiple factors. Climate change is an important factor in threats to human security through (1) undermining livelihoods, (2) compromising culture and identity, (3) increasing migration that people would rather have avoided, and (4) challenging the ability of states to provide the conditions necessary for human security. See Figure TS.11. [12.1 to 12.4, 12.6]

Climate change will compromise the cultural values that are important for community and individual well-being (*medium evidence*, *high agreement*). The effect of climate change on culture will vary across societies and over time, depending on cultural resilience and the mechanisms for maintaining and transferring knowledge. Changing weather and climatic conditions threaten cultural practices

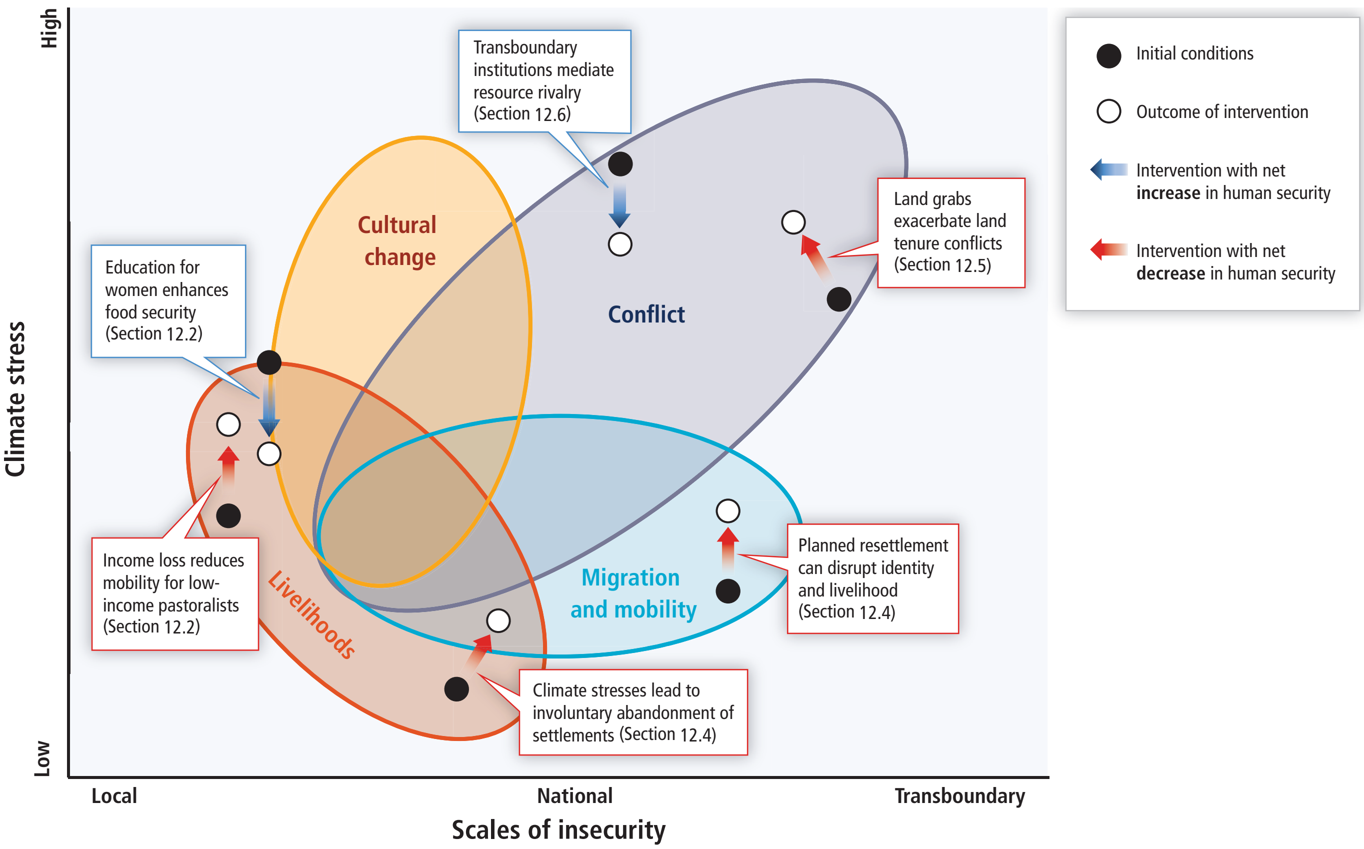


Figure TS.11 | Schematic of climate change risks for human security and the interactions between livelihoods, conflict, culture, and migration. Interventions and policies are indicated by the difference between initial conditions (solid black circles) and the outcome of intervention (white circles). Some interventions (blue arrows) show net increase in human security while others (red arrows) lead to net decrease in human security. [Figure 12-3]

embedded in livelihoods and expressed in narratives, worldviews, identity, community cohesion, and sense of place. Loss of land and displacement, for example, on small islands and coastal communities, have well documented negative cultural and well-being impacts. [12.3, 12.4]

Climate change over the 21st century is projected to increase displacement of people (*medium evidence*, *high agreement*). Displacement risk increases when populations that lack the resources for planned migration experience higher exposure to extreme weather events, in both rural and urban areas, particularly in developing countries with low income. Expanding opportunities for mobility can reduce vulnerability for such populations. Changes in migration patterns can be responses to both extreme weather events and longer-term climate variability and change, and migration can also be an effective adaptation strategy. There is *low confidence* in quantitative projections of changes in mobility, due to its complex, multi-causal nature. [9.3, 12.4, 19.4, 22.3, 25.9]

Climate change can indirectly increase risks of violent conflicts in the form of civil war and inter-group violence by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (*medium confidence*). Multiple lines of evidence relate climate variability to these forms of conflict. [12.5, 13.2, 19.4]

The impacts of climate change on the critical infrastructure and territorial integrity of many states are expected to influence national security policies (*medium evidence*, *medium agreement*). For example, land inundation due to sea level rise poses risks to the territorial integrity of small island states and states with extensive coastlines. Some transboundary impacts of climate change, such as changes in sea ice, shared water resources, and pelagic fish stocks, have the potential to increase rivalry among states, but robust national and intergovernmental institutions can enhance cooperation and manage many of these rivalries. [12.5, 12.6, 23.9, 25.9]

Livelihoods and Poverty

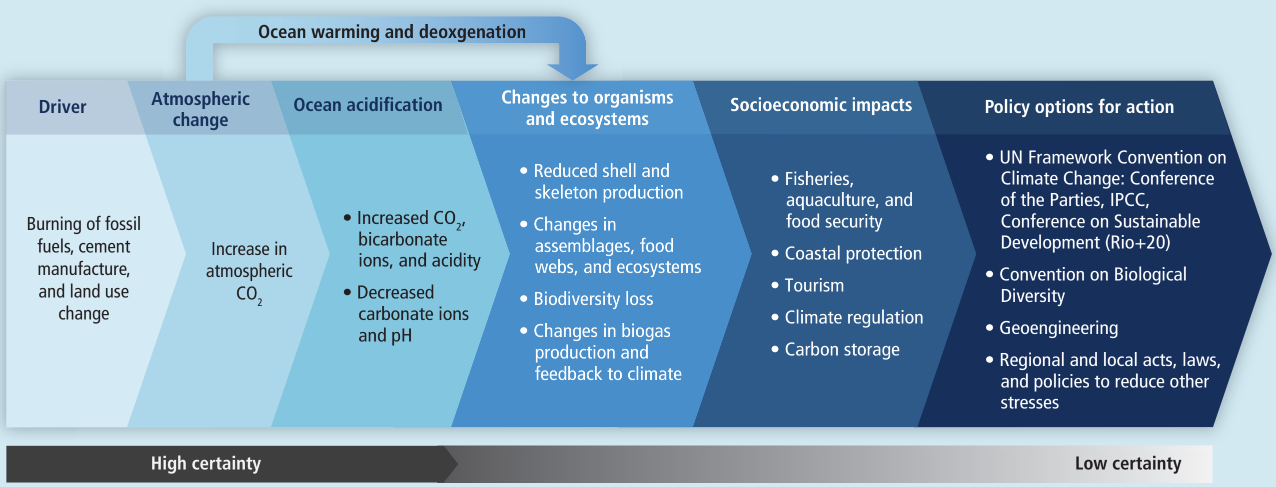
Throughout the 21st century, climate-change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security, and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger (*medium confidence*). Climate-change impacts are expected to exacerbate poverty in most developing countries and create new poverty pockets in countries with increasing inequality, in both developed and developing countries. In urban and rural areas, wage-labor-dependent poor households that are net buyers of food are expected to be particularly affected due to food price increases, including in regions with high food insecurity and high inequality (particularly in Africa), although the agricultural self-employed could benefit. Insurance programs, social protection measures, and disaster risk management may enhance long-term livelihood resilience

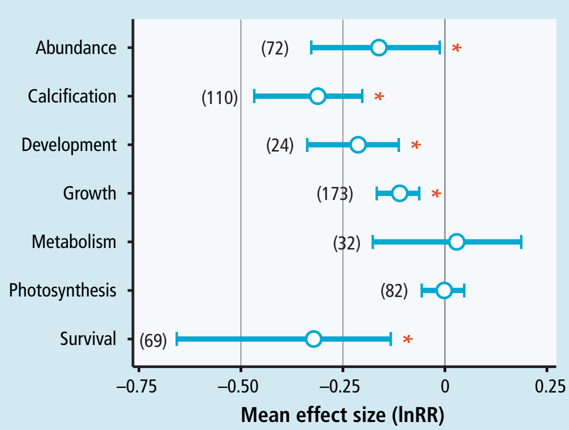
TS

Box TS.7 | Ocean Acidification

Anthropogenic ocean acidification and global warming share the same primary cause, which is the increase of atmospheric CO_2 (Box TS.7 Figure 1A). [WGI AR5 2.2] Eutrophication, upwelling, and deposition of atmospheric nitrogen and sulfur contribute to ocean acidification locally. [5.3, 6.1, 30.3] The fundamental chemistry of ocean acidification is well understood (*robust evidence*, *high agreement*). [30.3; WGI AR5 3.8, 6.4] It has been more difficult to understand and project changes within the more complex coastal systems. [5.3, 30.3]

Ocean acidification acts together with other global changes (e.g., warming, decreasing oxygen levels) and with local changes (e.g., pollution, eutrophication) (*high confidence*). Simultaneous drivers, such as warming and ocean acidification, can lead to interactive, complex, and amplified impacts for species and ecosystems. A pattern of positive and negative impacts of ocean acidification emerges for processes and organisms (*high confidence*; Box TS.7 Figure 1B), but key uncertainties remain from organismal to ecosystem levels. A wide range of sensitivities exists within and across organisms, with higher sensitivity in early life stages. [6.3] Lower pH decreases the rate of calcification of most, but not all, sea floor calcifiers, reducing their competitiveness with non-calcifiers (*robust evidence*, *medium agreement*). [5.4, 6.3] Ocean acidification stimulates dissolution of calcium carbonate (*very high confidence*). Growth and primary production are stimulated in seagrasses and some phytoplankton (*high confidence*), and harmful algal blooms could become more frequent (*limited evidence*, *medium agreement*). Serious behavioral disturbances have been reported in fishes





Box TS.7 Figure 1 | (A) Overview of the chemical, biological, and socioeconomic impacts of ocean acidification and of policy options. (B) Effect of near-future acidification (seawater pH reduction of ≤0.5 units) on major response variables estimated using weighted random effects meta-analyses, with the exception of survival, which is not weighted. The log-transformed response ratio (lnRR) is the ratio of the mean effect in the acidification treatment to the mean effect in a control group. It indicates which process is most uniformly affected by ocean acidification, but large variability exists between species. Significance is determined when the 95% bootstrapped confidence interval does not cross zero. The number of experiments used in the analyses is shown in parentheses. The * denotes a statistically significant effect. [Figure OA-1, Box CC-OA]

Continued next page →

Box TS.7 (continued)

(*high confidence*). [6.3] Natural analogs at CO_2 vents indicate decreased species diversity, biomass, and trophic complexity. Shifts in organisms' performance and distribution will change both predator-prey and competitive interactions, which could impact food webs and higher trophic levels (*limited evidence*, *high agreement*). [6.3]

A few studies provide *limited evidence* for adaptation in phytoplankton and mollusks. However, mass extinctions in Earth history occurred during much slower rates of change in ocean acidification, combined with other drivers, suggesting that evolutionary rates may be too slow for sensitive and long-lived species to adapt to the projected rates of future change (*medium confidence*). [6.1]

The biological, ecological, and biogeochemical changes driven by ocean acidification will affect key ecosystem services. The oceans will become less efficient at absorbing CO_2 and hence moderating climate (*very high confidence*). [WGI AR5 Figure 6.26] The impacts of ocean acidification on coral reefs, together with those of thermal stress (driving mass coral bleaching and mortality) and sea level rise, will diminish their role in shoreline protection as well as their direct and indirect benefits to fishing and tourism industries (*limited evidence*, *high agreement*). [Box CC-CR] The global cost of production loss of mollusks could be over US$100 billion by 2100 (*low confidence*). The largest uncertainty is how the impacts on lower trophic levels will propagate through the food webs and to top predators. Models suggest that ocean acidification will generally reduce fish biomass and catch (*low confidence*) and complex additive, antagonistic, and/or synergistic interactions will occur with disruptive ramifications for ecosystems as well as for important ecosystem goods and services.

among poor and marginalized people, if policies address poverty and multidimensional inequalities. [8.1, 8.3, 8.4, 9.3, 10.9, 13.2 to 13.4, 22.3, 26.8]

B-3. Regional Risks and Potential for Adaptation

Risks will vary through time across regions and populations, dependent on myriad factors including the extent of adaptation and mitigation. A selection of key regional risks identified with *medium* to *high confidence* is presented in Table TS.5. Projected changes in climate and increasing atmospheric CO_2 will have positive effects for some sectors in some locations. For extended summary of regional risks and the more limited potential benefits, see introductory overviews for each region below and also WGII AR5 Part B: Regional Aspects, Chapters 21 to 30.

***Africa*. Climate change will amplify existing stress on water availability and on agricultural systems particularly in semi-arid environments (*high confidence*).** Increasing temperatures and changes in precipitation are *very likely* to reduce cereal crop productivity with strong adverse effects on food security (*high confidence*). Progress has been achieved on managing risks to food production from current climate variability and near-term climate change, but this will not be sufficient to address long-term impacts of climate change. Adaptive agricultural processes such as collaborative, participatory research that includes scientists and farmers, strengthened communication systems for anticipating and responding to climate risks, and increased flexibility in livelihood options provide potential pathways for strengthening adaptive capacities. Climate change is a multiplier of existing health vulnerabilities including insufficient access to safe water and improved sanitation, food insecurity, and limited access to health care and education. Strategies that integrate consideration of climate change risks with land and water management and disaster risk reduction bolster resilient development. [22.3 to 22.4, 22.6]

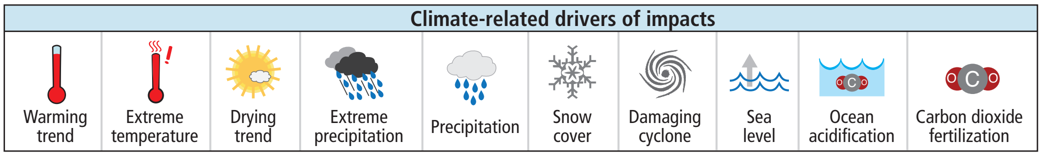
***Europe*. Climate change will increase the likelihood of systemic failures across European countries caused by extreme climate events affecting multiple sectors (*medium confidence*).** Sea level rise and increases in extreme rainfall are projected to further increase coastal and river flood risks and without adaptive measures will substantially increase flood damages (i.e., people affected and economic losses); adaptation can prevent most of the projected damages (*high confidence*). Heat-related deaths and injuries are *likely* to increase, particularly in southern Europe (*medium confidence*). Climate change is *likely* to increase cereal crop yields in northern Europe (*medium confidence*) but decrease yields in southern Europe (*high confidence*). Climate change will increase irrigation needs in Europe, and future irrigation will be constrained by reduced runoff, demand from other sectors, and economic costs, with integrated water management a strategy for addressing competing demands. Hydropower production is *likely* to decrease in all sub-regions except Scandinavia. Climate change is *very likely* to cause changes in habitats and species, with local extinctions (*high confidence*), continental-scale shifts in species distributions (*medium confidence*), and significantly reduced alpine plant habitat (*high confidence*). Climate change is *likely* to entail the loss or displacement of coastal wetlands. The introduction and expansion of invasive species, especially those with high migration rates, from outside Europe is *likely* to increase with climate change (medium confidence). [23.2 to 23.9]

***Asia*. Climate change will cause declines in agricultural productivity in many sub-regions of Asia, for crops such as rice (*medium confidence*).** In Central Asia, cereal production in northern and eastern Kazakhstan could benefit from the longer growing season, warmer winters, and slight increase in winter precipitation, while droughts in western Turkmenistan and Uzbekistan could negatively affect cotton production, increase water demand for irrigation, and exacerbate desertification. The effectiveness of potential and practiced agricultural adaptation strategies is not well understood. Future projections of precipitation at sub-regional scales and thus of freshwater availability in most parts of Asia are uncertain (*low confidence* in projections), but increased water demand from population growth, increased water consumption per capita, and lack of good management will increase water scarcity challenges for most of the region (*medium confidence*). Adaptive responses include integrated water management strategies, such as development of water-saving technologies, increased water productivity, and water reuse. Extreme climate events will have an increasing impact on human health, security, livelihoods, and poverty, with the type and magnitude of impact varying across Asia (*high confidence*). In many parts of Asia, observed terrestrial impacts, such as permafrost degradation and shifts in plant species' distributions, growth rates, and timing of seasonal activities, will increase due to climate change projected during the 21st century. Coastal and marine systems in Asia, such as mangroves, seagrass beds, salt marshes, and coral reefs, are under increasing stress from climatic and non-climatic drivers. In the Asian Arctic, sea level rise interacting with projected changes in permafrost and the length of the ice-free season will increase rates of coastal erosion (*medium evidence*, *high agreement*). [24.4, 30.5]

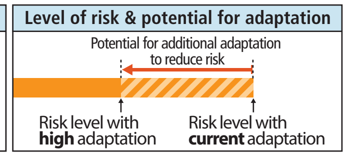
***Australasia*. Without adaptation, further changes in climate, atmospheric carbon dioxide, and ocean acidity are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture, and biodiversity (*high confidence*).** Freshwater resources are projected to decline in far

Table TS.5 | Key regional risks from climate change and the potential for reducing risks through adaptation and mitigation. Key risks have been identified based on assessment of the relevant scientific, technical, and socioeconomic literature detailed in supporting chapter sections. Identification of key risks was based on expert judgment using the following specific criteria: large magnitude, high probability, or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation. Each key risk is characterized as very low to very high for three timeframes: the present, near term (here, assessed over 2030–2040), and longer term (here, assessed over 2080–2100). The risk levels integrate probability and consequence over the widest possible range of potential outcomes, based on available literature. These potential outcomes result from the interaction of climate-related hazards, vulnerability, and exposure. Each risk level reflects total risk from climatic and non-climatic factors. For the near-term era of committed climate change, projected levels of global mean temperature increase do not diverge substantially for different emission scenarios. For the longer-term era of climate options, risk levels are presented for two scenarios of global mean temperature increase (2°C and 4°C above preindustrial levels). These scenarios illustrate the potential for mitigation and adaptation to reduce the risks related to climate change. For the present, risk levels were estimated for current adaptation and a hypothetical highly adapted state, identifying where current adaptation deficits exist. For the two future timeframes, risk levels were estimated for a continuation of current adaptation and for a highly adapted state, representing the potential for and limits to adaptation. Climate-related drivers of impacts are indicated by icons. Key risks and risk levels vary across regions and over time, given differing socioeconomic development pathways, vulnerability and exposure to hazards, adaptive capacity, and risk perceptions. Risk levels are not necessarily comparable, especially across regions, because the assessment considers potential impacts and adaptation in different physical, biological, and human systems across diverse contexts. This assessment of risks acknowledges the importance of differences in values and objectives in interpretation of the assessed risk levels.

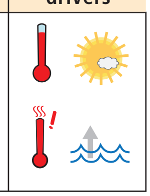
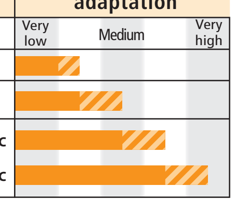
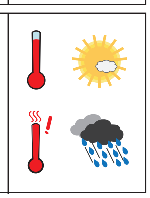
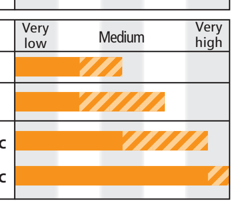
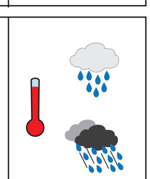
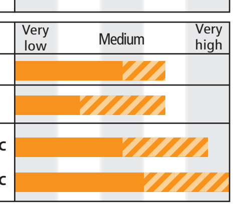
Climate-related drivers of impacts



Level of risk & potential for adaptation



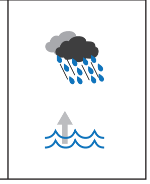
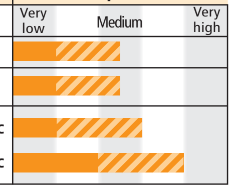
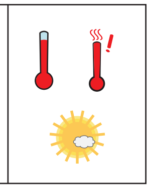
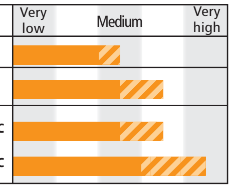
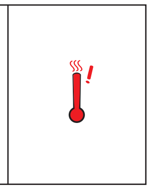
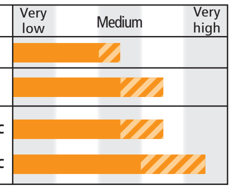
Africa

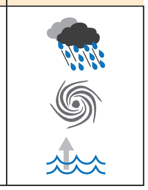
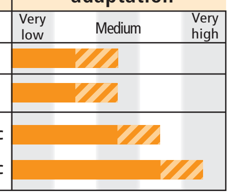
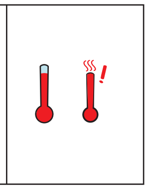
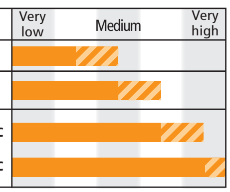
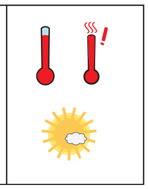
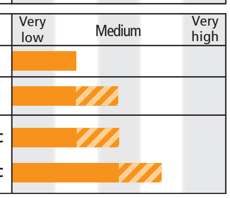
Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Compounded stress on water resources facing significant strain from overexploitation and degradation at present and increased demand in the future, with drought stress exacerbated in drought-prone regions of Africa (*high confidence*) [22.3, 22.4]	• Reducing non-climate stressors on water resources • Strengthening institutional capacities for demand management, groundwater assessment, integrated water-wastewater planning, and integrated land and water governance • Sustainable urban development		Present; Near term (2030–2040); Long term (2080–2100) 2°C, 4°C	
Reduced crop productivity associated with heat and drought stress, with strong adverse effects on regional, national, and household livelihood and food security, also given increased pest and disease damage and flood impacts on food system infrastructure (*high confidence*) [22.3, 22.4]	• Technological adaptation responses (e.g., stress-tolerant crop varieties, irrigation, enhanced observation systems) • Enhancing smallholder access to credit and other critical production resources; Diversifying livelihoods • Strengthening institutions at local, national, and regional levels to support agriculture (including early warning systems) and gender-oriented policy • Agronomic adaptation responses (e.g., agroforestry, conservation agriculture)		Present; Near term (2030–2040); Long term (2080–2100) 2°C, 4°C	
Changes in the incidence and geographic range of vector- and water-borne diseases due to changes in the mean and variability of temperature and precipitation, particularly along the edges of their distribution (*medium confidence*) [22.3]	• Achieving development goals, particularly improved access to safe water and improved sanitation, and enhancement of public health functions such as surveillance • Vulnerability mapping and early warning systems • Coordination across sectors • Sustainable urban development		Present; Near term (2030–2040); Long term (2080–2100) 2°C, 4°C	

Continued next page →

Table TS.5 (continued)

Continued next page →

Europe				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Increased economic losses and people affected by flooding in river basins and coasts, driven by increasing urbanization, increasing sea levels, coastal erosion, and peak river discharges (*high confidence*) [23.2, 23.3, 23.7]	Adaptation can prevent most of the projected damages (*high confidence*). • Significant experience in hard flood-protection technologies and increasing experience with restoring wetlands • High costs for increasing flood protection • Potential barriers to implementation: demand for land in Europe and environmental and landscape concerns		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Increased water restrictions. Significant reduction in water availability from river abstraction and from groundwater resources, combined with increased water demand (e.g., for irrigation, energy and industry, domestic use) and with reduced water drainage and runoff as a result of increased evaporative demand, particularly in southern Europe (*high confidence*) [23.4, 23.7]	• Proven adaptation potential from adoption of more water-efficient technologies and of water-saving strategies (e.g., for irrigation, crop species, land cover, industries, domestic use) • Implementation of best practices and governance instruments in river basin management plans and integrated water management		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Increased economic losses and people affected by extreme heat events: impacts on health and well-being, labor productivity, crop production, air quality, and increasing risk of wildfires in southern Europe and in Russian boreal region (*medium confidence*) [23.3 to 23.7, Table 23-1]	• Implementation of warning systems • Adaptation of dwellings and workplaces and of transport and energy infrastructure • Reductions in emissions to improve air quality • Improved wildfire management • Development of insurance products against weather-related yield variations		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	

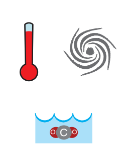
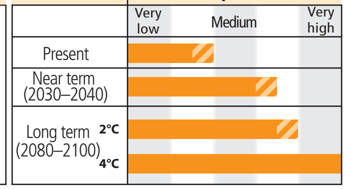
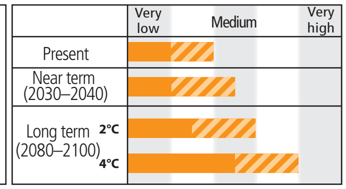
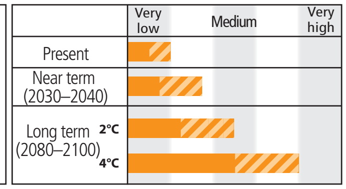
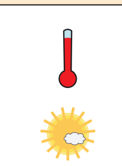
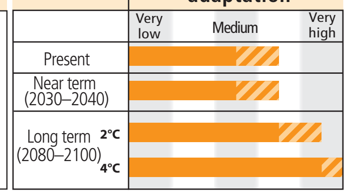
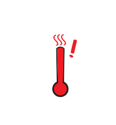
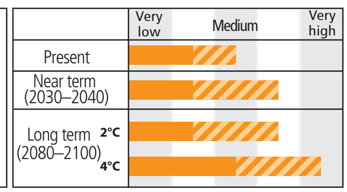
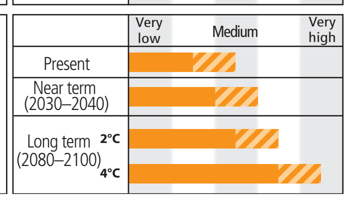
Asia				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Increased riverine, coastal, and urban flooding leading to widespread damage to infrastructure, livelihoods, and settlements in Asia (*medium confidence*) [24.4]	• Exposure reduction via structural and non-structural measures, effective land-use planning, and selective relocation • Reduction in the vulnerability of lifeline infrastructure and services (e.g., water, energy, waste management, food, biomass, mobility, local ecosystems, telecommunications) • Construction of monitoring and early warning systems; Measures to identify exposed areas, assist vulnerable areas and households, and diversify livelihoods • Economic diversification		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Increased risk of heat-related mortality (*high confidence*) [24.4]	• Heat health warning systems • Urban planning to reduce heat islands; Improvement of the built environment; Development of sustainable cities • New work practices to avoid heat stress among outdoor workers		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Increased risk of drought-related water and food shortage causing malnutrition (*high confidence*) [24.4]	• Disaster preparedness including early-warning systems and local coping strategies • Adaptive/integrated water resource management • Water infrastructure and reservoir development • Diversification of water sources including water re-use • More efficient use of water (e.g., improved agricultural practices, irrigation management, and resilient agriculture)		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	

southwest and far southeast mainland Australia (*high confidence*) and for some rivers in New Zealand (*medium confidence*). Rising sea levels and increasing heavy rainfall are projected to increase erosion and inundation, with consequent damages to many low-lying ecosystems, infrastructure, and housing (*high confidence*); increasing heat waves will increase risks to human health; rainfall changes and rising temperatures will shift agricultural production zones; and many native species will suffer from range contractions and some may face local or even global extinction. Uncertainty in projected rainfall changes remains large for many parts of Australia and New Zealand, which creates significant challenges for adaptation. Some sectors in some locations have the potential to benefit from projected changes in climate and increasing atmospheric CO_2, for example due to reduced energy demand for winter heating in New Zealand and southern parts of Australia, and due to forest growth in cooler regions except where soil nutrients or rainfall are limiting. Indigenous peoples in both Australia and New Zealand have higher than average exposure to climate change due to a heavy reliance on climate-sensitive primary industries and strong social connections to the natural environment, and face additional constraints to adaptation (*medium confidence*). [25.2, 25.3, 25.5 to 25.8, Boxes 25-1, 25-2, 25-5, and 25-8]

***North America*. Many climate-related hazards that carry risk, particularly related to severe heat, heavy precipitation, and declining snowpack, will increase in frequency and/or severity in North America in the next decades (*very high confidence*).** Climate

Table TS.5 (continued)

Continued next page →

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe / Risk & potential for adaptation
Australasia			
Significant change in community composition and structure of coral reef systems in Australia (*high confidence*) [25.6, 30.5, Boxes CC-CR and CC-OA]	• Ability of corals to adapt naturally appears limited and insufficient to offset the detrimental effects of rising temperatures and acidification. • Other options are mostly limited to reducing other stresses (water quality, tourism, fishing) and early warning systems; direct interventions such as assisted colonization and shading have been proposed but remain untested at scale.		
Increased frequency and intensity of flood damage to infrastructure and settlements in Australia and New Zealand (*high confidence*) [Table 25-1, Boxes 25-8 and 25-9]	• Significant adaptation deficit in some regions to current flood risk. • Effective adaptation includes land-use controls and relocation as well as protection and accommodation of increased risk to ensure flexibility.		
Increasing risks to coastal infrastructure and low-lying ecosystems in Australia and New Zealand, with widespread damage towards the upper end of projected sea-level-rise ranges (*high confidence*) [25.6, 25.10, Box 25-1]	• Adaptation deficit in some locations to current coastal erosion and flood risk. Successive building and protection cycles constrain flexible responses. • Effective adaptation includes land-use controls and ultimately relocation as well as protection and accommodation.		
North America			
Wildfire-induced loss of ecosystem integrity, property loss, human morbidity, and mortality as a result of increased drying trend and temperature trend (*high confidence*) [26.4, 26.8, Box 26-2]	• Some ecosystems are more fire-adapted than others. Forest managers and municipal planners are increasingly incorporating fire protection measures (e.g., prescribed burning, introduction of resilient vegetation). Institutional capacity to support ecosystem adaptation is limited. • Adaptation of human settlements is constrained by rapid private property development in high-risk areas and by limited household-level adaptive capacity. • Agroforestry can be an effective strategy for reduction of slash and burn practices in Mexico.		
Heat-related human mortality (*high confidence*) [26.6, 26.8]	• Residential air conditioning (A/C) can effectively reduce risk. However, availability and usage of A/C is highly variable and is subject to complete loss during power failures. Vulnerable populations include athletes and outdoor workers for whom A/C is not available. • Community- and household-scale adaptations have the potential to reduce exposure to heat extremes via family support, early heat warning systems, cooling centers, greening, and high-albedo surfaces.		
Urban floods in riverine and coastal areas, inducing property and infrastructure damage; supply chain, ecosystem, and social system disruption; public health impacts; and water quality impairment, due to sea level rise, extreme precipitation, and cyclones (*high confidence*) [26.2 to 26.4, 26.8]	• Implementing management of urban drainage is expensive and disruptive to urban areas. • Low-regret strategies with co-benefits include less impervious surfaces leading to more groundwater recharge, green infrastructure, and rooftop gardens. • Sea level rise increases water elevations in coastal outfalls, which impedes drainage. In many cases, older rainfall design standards are being used that need to be updated to reflect current climate conditions. • Conservation of wetlands, including mangroves, and land-use planning strategies can reduce the intensity of flood events.		

change will amplify risks to water resources already affected by non-climatic stressors, with potential impacts associated with decreased snowpack, decreased water quality, urban flooding, and decreased water supplies for urban areas and irrigation (*high confidence*). More adaptation options are available to address water supply deficits than flooding and water quality concerns (*medium confidence*). Ecosystems are under increasing stress from rising temperatures, CO_2 concentrations, and sea levels, with particular vulnerability to climate extremes (*very high confidence*). In many cases, climate stresses exacerbate other anthropogenic influences on ecosystems, including land use changes, non-native species, and pollution. Projected increases in temperature, reductions in precipitation in some regions, and increased frequency of extreme events would result in net productivity declines in major North American crops by the end of the 21st century without adaptation, although some regions, particularly in the north, may benefit. Adaptation, often with mitigation co-benefits, could offset projected negative yield impacts for many crops at 2°C global mean temperature increase above preindustrial levels, with reduced effectiveness of adaptation at 4°C (*high confidence*). Although larger urban centers would have higher adaptive capacities, high population density, inadequate infrastructures, lack of institutional capacity, and degraded natural environments increase future climate risks from heat waves, droughts, storms, and sea level rise (*medium evidence*, *high agreement*). Future risks from climate extremes can be reduced, for example through targeted and sustainable air conditioning, more effective warning and response systems, enhanced pollution controls, urban

Table TS.5 (continued)

Continued next page →

Central and South America

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Water availability in semi-arid and glacier-melt-dependent regions and Central America; flooding and landslides in urban and rural areas due to extreme precipitation (*high confidence*) [27.3]	• Integrated water resource management • Urban and rural flood management (including infrastructure), early warning systems, better weather and runoff forecasts, and infectious disease control		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Decreased food production and food quality (*medium confidence*) [27.3]	• Development of new crop varieties more adapted to climate change (temperature and drought) • Offsetting of human and animal health impacts of reduced food quality • Offsetting of economic impacts of land-use change • Strengthening traditional indigenous knowledge systems and practices		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Spread of vector-borne diseases in altitude and latitude (*high confidence*) [27.3]	• Development of early warning systems for disease control and mitigation based on climatic and other relevant inputs. Many factors augment vulnerability. • Establishing programs to extend basic public health services		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high Long term 2°C: not available Long term 4°C: not available

Polar Regions

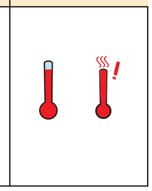
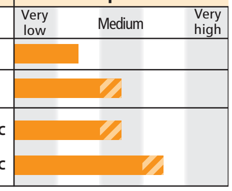
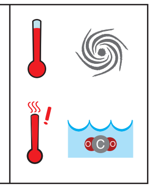
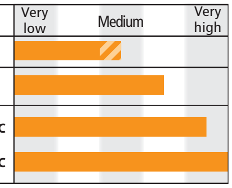
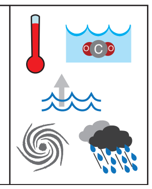
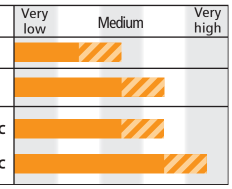
Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Risks for freshwater and terrestrial ecosystems (*high confidence*) and marine ecosystems (*medium confidence*), due to changes in ice, snow cover, permafrost, and freshwater/ocean conditions, affecting species´ habitat quality, ranges, phenology, and productivity, as well as dependent economies [28.2 to 28.4]	• Improved understanding through scientific and indigenous knowledge, producing more effective solutions and/or technological innovations • Enhanced monitoring, regulation, and warning systems that achieve safe and sustainable use of ecosystem resources • Hunting or fishing for different species, if possible, and diversifying income sources		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Risks for the health and well-being of Arctic residents, resulting from injuries and illness from the changing physical environment, food insecurity, lack of reliable and safe drinking water, and damage to infrastructure, including infrastructure in permafrost regions (*high confidence*) [28.2 to 28.4]	• Co-production of more robust solutions that combine science and technology with indigenous knowledge • Enhanced observation, monitoring, and warning systems • Improved communications, education, and training • Shifting resource bases, land use, and/or settlement areas		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Unprecedented challenges for northern communities due to complex inter-linkages between climate-related hazards and societal factors, particularly if rate of change is faster than social systems can adapt (*high confidence*) [28.2 to 28.4]	• Co-production of more robust solutions that combine science and technology with indigenous knowledge • Enhanced observation, monitoring, and warning systems • Improved communications, education, and training • Adaptive co-management responses developed through the settlement of land claims		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high

Small Islands

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Loss of livelihoods, coastal settlements, infrastructure, ecosystem services, and economic stability (*high confidence*) [29.6, 29.8, Figure 29-4]	• Significant potential exists for adaptation in islands, but additional external resources and technologies will enhance response. • Maintenance and enhancement of ecosystem functions and services and of water and food security • Efficacy of traditional community coping strategies is expected to be substantially reduced in the future.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
The interaction of rising global mean sea level in the 21st century with high-water-level events will threaten low-lying coastal areas (*high confidence*) [29.4, Table 29-1; WGI AR5 13.5, Table 13.5]	• High ratio of coastal area to land mass will make adaptation a significant financial and resource challenge for islands. • Adaptation options include maintenance and restoration of coastal landforms and ecosystems, improved management of soils and freshwater resources, and appropriate building codes and settlement patterns.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high

TS

Table TS.5 (continued)

The Ocean				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Distributional shift in fish and invertebrate species, and decrease in fisheries catch potential at low latitudes, e.g., in equatorial upwelling and coastal boundary systems and sub-tropical gyres (*high confidence*) [6.3, 30.5, 30.6, Tables 6-6 and 30-3, Box CC-MB]	• Evolutionary adaptation potential of fish and invertebrate species to warming is limited as indicated by their changes in distribution to maintain temperatures. • Human adaptation options: Large-scale translocation of industrial fishing activities following the regional decreases (low latitude) vs. possibly transient increases (high latitude) in catch potential; Flexible management that can react to variability and change; Improvement of fish resilience to thermal stress by reducing other stressors such as pollution and eutrophication; Expansion of sustainable aquaculture and the development of alternative livelihoods in some regions.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Reduced biodiversity, fisheries abundance, and coastal protection by coral reefs due to heat-induced mass coral bleaching and mortality increases, exacerbated by ocean acidification, e.g., in coastal boundary systems and sub-tropical gyres (*high confidence*) [5.4, 6.4, 30.3, 30.5, 30.6, Tables 6-6 and 30-3, Box CC-CR]	• Evidence of rapid evolution by corals is very limited. Some corals may migrate to higher latitudes, but entire reef systems are not expected to be able to track the high rates of temperature shifts. • Human adaptation options are limited to reducing other stresses, mainly by enhancing water quality, and limiting pressures from tourism and fishing. These options will delay human impacts of climate change by a few decades, but their efficacy will be severely reduced as thermal stress increases.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Coastal inundation and habitat loss due to sea level rise, extreme events, changes in precipitation, and reduced ecological resilience, e.g., in coastal boundary systems and sub-tropical gyres (*medium* to *high confidence*) [5.5, 30.5, 30.6, Tables 6-6 and 30-3, Box CC-CR]	• Human adaptation options are limited to reducing other stresses, mainly by reducing pollution and limiting pressures from tourism, fishing, physical destruction, and unsustainable aquaculture. • Reducing deforestation and increasing reforestation of river catchments and coastal areas to retain sediments and nutrients • Increased mangrove, coral reef, and seagrass protection, and restoration to protect numerous ecosystem goods and services such as coastal protection, tourist value, and fish habitat		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	

planning strategies, and resilient health infrastructure (*high confidence*). [26.3 to 26.6, 26.8]

***Central and South America*. Despite improvements, high and persistent levels of poverty in most countries result in high vulnerability to climate variability and change (*high confidence*).** Climate change impacts on agricultural productivity are expected to exhibit large spatial variability, for example with sustained or increased productivity through mid-century in southeast South America and decreases in productivity in the near term (by 2030) in Central America, threatening food security of the poorest populations (*medium confidence*). Reduced precipitation and increased evapotranspiration in semi-arid regions will increase risks from water-supply shortages, affecting cities, hydropower generation, and agriculture (*high confidence*). Ongoing adaptation strategies include reduced mismatch between water supply and demand, and water-management and coordination reforms (*medium confidence*). Conversion of natural ecosystems, a driver of anthropogenic climate change, is the main cause of biodiversity and ecosystem loss (*high confidence*). Climate change is expected to increase rates of species extinction (*medium confidence*). In coastal and marine systems, sea level rise and human stressors increase risks for fish stocks, corals, mangroves, recreation and tourism, and control of diseases (*high confidence*). Climate change will exacerbate future health risks given regional population growth rates and vulnerabilities due to pollution, food insecurity in poor regions, and existing health, water, sanitation, and waste collection systems (*medium confidence*). [27.2, 27.3]

***Polar Regions*. Climate change and often-interconnected non-climate-related drivers, including environmental changes, demography, culture, and economic development, interact in the Arctic to determine physical, biological, and socioeconomic risks, with rates of change that may be faster than social systems can adapt (*high confidence*).** Thawing permafrost and changing precipitation patterns have the potential to affect infrastructure and related services, with particular risks for residential buildings, for example in Arctic cities and small rural settlements. Climate change will especially impact Arctic communities that have narrowly based economies limiting adaptive choices. Increased Arctic navigability and expanded land- and freshwater-based transportation networks will increase economic opportunities. Impacts on the informal, subsistence-based economy will include changing sea ice conditions that increase the difficulty of hunting marine mammals. Polar bears have been and will be affected by loss of annual ice over continental shelves, decreased ice duration, and decreased ice thickness. Already, accelerated rates of change in permafrost thaw, loss of coastal sea ice, sea level rise, and increased intensity of weather extremes are forcing relocation of some indigenous communities in Alaska (*high confidence*). In the Arctic and Antarctic, some marine species will shift their ranges in response to changing ocean and sea ice conditions (*medium confidence*). Climate change will increase the vulnerability of terrestrial ecosystems to invasions by non-indigenous species (*high confidence*). [6.3, 6.5, 28.2 to 28.4]

***Small Islands*. Small islands have high vulnerability to climatic and non-climatic stressors (*high confidence*).** Diverse physical and human attributes and their sensitivity to climate-related drivers lead to variable climate change risk profiles and adaptation from one island region to another and among countries in the same region. Risks can originate from transboundary interactions, for example associated with existing and future invasive species and human health challenges. Sea level rise poses one of the most widely recognized climate change threats to low-lying coastal areas on islands and atolls. Projected sea level rise at the end of the 21st century, superimposed on extreme-sea-level events, presents severe coastal flooding and erosion risks for low-lying coastal areas and atoll islands. Wave over-wash will degrade groundwater resources. Coral reef ecosystem degradation associated with increasing sea surface temperature and ocean acidification will

Table TS.6 | Observed and projected future changes in some types of temperature and precipitation extremes over 26 sub-continental regions as defined in the IPCC *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX). Confidence levels are indicated by symbol color. Likelihood terms are given only for *high* or *very high confidence* statements. Observed trends in temperature and precipitation extremes, including dryness and drought, are generally calculated from 1950, using 1961–1990 as the reference period, unless otherwise indicated. Future changes are derived from global and regional climate model projections for 2071–2100 compared with 1961–1990 or for 2080–2100 compared with 1980–2000. Table entries are summaries of information in SREX Tables 3-2 and 3-3 supplemented with or superseded by material from WGI AR5 2.6, 14.8, and Table 2.13 and WGII AR5 Table 25-1. The source(s) of information for each entry are indicated by superscripts: (a) SREX Table 3-2; (b) SREX Table 3-3; (c) WGI AR5 2.6 and Table 2.13; (d) WGI AR5 14.8; (e) WGII AR5 Table 25-1. [Tables 21-7 and SM21-2, Figure 21-4]

Region/ region code	Trends in daytime temperature extremes (frequency of hot and cool days)		Trends in heavy precipitation (rain, snow)		Trends in dryness and drought	
	Observed	Projected	Observed	Projected	Observed	Projected
West North America WNA, 3	*Very likely* large increases in hot days (large decreases in cool days)[a]	*Very likely* increase in hot days (decrease in cool days)[b]	Spatially varying trends. General increase, decrease in some areas[a]	Increase in 20-year return value of annual maximum daily precipitation and other metrics over northern part of the region (Canada)[b] Less confidence in southern part of the region, due to inconsistent signal in these other metrics[b]	No change or overall slight decrease in dryness[a]	Inconsistent signal[b]
Central North America CNA, 4	Spatially varying trends: small increases in hot days in the north, decreases in the south[a]	*Very likely* increase in hot days (decrease in cool days)[b]	*Very likely* increase since 1950[a]	Increase in 20-year return value of annual maximum daily precipitation[b] Inconsistent signal in other heavy precipitation days metrics[b]	*Likely* decrease[a, c]	Increase in consecutive dry days and soil moisture in southern part of central North America[b] Inconsistent signal in the rest of the region[b]
East North America ENA, 5	Spatially varying trends. Overall increases in hot days (decreases in cool days), opposite or insignificant signal in a few areas[a]	*Very likely* increase in hot days (decrease in cool days)[b]	*Very likely* increase since 1950[a]	Increase in 20-year return value of annual maximum daily precipitation. Additional metrics support an increase in heavy precipitation over northern part of the region.[b] No signal or inconsistent signal in these other metrics in the southern part of the region[b]	Slight decrease in dryness since 1950[a]	Inconsistent signal in consecutive dry days, some consistent decrease in soil moisture[b]
Alaska/ Northwest Canada ALA, 1	*Very likely* large increases in hot days (decreases in cool days)[a]	*Very likely* increase in hot days (decrease in cool days)[b]	Slight tendency for increase[a] No significant trend in southern Alaska[a]	*Likely* increase in heavy precipitation[b]	Inconsistent trends[a] Increase in dryness in part of the region[a]	Inconsistent signal[b]
East Canada, Greenland, Iceland CGI, 2	*Likely* increases in hot days (decreases in cool days) in some areas, decrease in hot days (increase in cool days) in others[a]	*Very likely* increase in hot days (decrease in cool days)[b]	Increase in a few areas[a]	*Likely* increase in heavy precipitation[b]	Insufficent evidence[a]	Inconsistent signal[b]
Northern Europe NEU, 11	Increase in hot days (decrease in cool days), but generally not significant at the local scale[a]	*Very likely* increase in hot days (decrease in cool days) [but smaller trends than in central and southern Europe][b]	Increase in winter in some areas, but often insignificant or inconsistent trends at sub-regional scale, particularly in summer[a]	*Likely* increase in 20-year return value of annual maximum daily precipitation. *Very likely* increases in heavy preciptation intensity and frequency in winter in the north[b]	Spatially varying trends. Overall only slight or no increase in dryness, slight decrease in dryness in part of the region[a]	No major changes in dryness[b]

Symbols

Increasing trend or signal · Decreasing trend or signal · Both increasing and decreasing trend or signal · Inconsistent trend or signal or insufficient evidence · No change or only slight change

Level of confidence in findings

Low confidence · *Medium confidence* · *High confidence*

Continued next page →

Table TS.6 (continued)

Region/ region code	Trends in daytime temperature extremes (frequency of hot and cool days)		Trends in heavy precipitation (rain, snow)		Trends in dryness and drought	
	Observed	Projected	Observed	Projected	Observed	Projected
Central Europe CEU, 12	*Likely* overall increase in hot days (decrease in cool days) in most regions. *Very likely* increase in hot days (*likely* decrease in cool days) in west-central Europe[a] Lower confidence in trends in east-central Europe (due to lack of literature, partial lack of access to observations, overall weaker signals, and change point in trends)[a]	*Very likely* increase in hot days (decrease in cool days)[b]	Increase in part of the region, in particular central western Europe and European Russia, especially in winter.[a] Insignificant or inconsistent trends elsewhere, in particular in summer[a]	*Likely* increase in 20-year return value of annual maximum daily precipitation. Additional metrics support an increase in heavy precipitation in large part of the region in winter.[b] Less confidence in summer, due to inconsistent evidence[b]	Spatially varying trends. Increase in dryness in part of the region but some regional variation in dryness trends and dependence of trends on studies considered (index, time period)[a]	Increase in dryness in central Europe and increase in short-term droughts[b]
Southern Europe and Mediterranean MED, 13	*Likely* increase in hot days (decrease in cool days) in most of the region. Some regional and temporal variations in the significance of the trends. *Likely* strongest and most significant trends in Iberian peninsula and southern France[a] Smaller or less significant trends in southeastern Europe and Italy due to change point in trends, strongest increase in hot days since 1976[a]	*Very likely* increase in hot days (decrease in cool days)[b]	Inconsistent trends across the region and across studies[a]	Inconsistent changes and/or regional variations[b]	Overall increase in dryness, *likely* increase in the Mediterranean[a, c]	Increase in dryness. Consistent increase in area of drought[b, d]
West Africa WAF, 15	Significant increase in temperature of hottest day and coolest day in some parts[a] Insufficient evidence in other parts[a]	*Likely* increase in hot days (decrease in cool days)[b]	Rainfall intensity increased[a]	Slight or no change in heavy precipitation indicators in most areas[b] Low model agreement in northern areas[b]	*Likely* increase but 1970s Sahel drought dominates the trend; greater inter-annual variation in recent years[a, c]	Inconsistent signal[b]
East Africa EAF, 16	Lack of evidence due to lack of literature and spatially non-uniform trends[a] Increases in hot days in southern tip (decreases in cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Insufficient evidence[a]	*Likely* increase in heavy precipitation[b]	Spatially varying trends in dryness[a]	Decreasing dryness in large areas[b]
Southern Africa SAF, 17	*Likely* increase in hot days (decrease in cool days)[a, c]	*Likely* increase in hot days (decrease in cool days)[b]	Increases in more regions than decreases but spatially varying trends[a,c]	Lack of agreement in signal for region as a whole[b] Some evidence of increase in heavy precipitation in southeast regions[b]	General increase in dryness[a]	Increase in dryness, except eastern part[b, d] Consistent increase in area of drought[b]
Sahara SAH, 14	Lack of literature[a]	*Likely* increase in hot days (decrease in cool days)[b]	Insufficient evidence[a]	*Low agreement*[b]	Limited data, spatial variation of the trends[a]	Inconsistent signal of change[b]
Central America and Mexico CAM, 6	Increases in the number of hot days, decreases in the number of cool days[a]	*Likely* increase in hot days (decrease in cool days)[b]	Spatially varying trends. Increase in many areas, decrease in a few others[a]	Inconsistent trends[b]	Varying and inconsistent trends[a]	Increase in dryness in Central America and Mexico, with less confidence in trend in extreme south of region[b]

Continued next page →

Table TS.6 (continued)

Region/ region code	Trends in daytime temperature extremes (frequency of hot and cool days)		Trends in heavy precipitation (rain, snow)		Trends in dryness and drought	
	Observed	Projected	Observed	Projected	Observed	Projected
Amazon AMZ, 7	Insufficient evidence to identify trends[a]	Hot days *likely* to increase (cool days *likely* to decrease)[b]	Increase in many areas, decrease in a few[a]	Tendency for increases in heavy precipitation events in some metrics[b]	Decrease in dryness for much of the region. Some opposite trends and inconsistencies[a]	Inconsistent signals[b]
Northeastern Brazil NEB, 8	Increases in the number of hot days[a]	Hot days *likely* to increase (cool days *likely* to decrease)[b]	Increase in many areas, decrease in a few[a]	Slight or no change[b]	Varying and inconsistent trends[a]	Increase in dryness[b]
Southeastern South America SSA, 10	Spatially varying trends (increases in hot days in some areas, decreases in others)[a]	Hot days *likely* to increase (cool days *likely* to decrease)[b]	Increase in northern areas[a] Insufficient evidence in southern areas[a]	Increases in northern areas[b] Insufficient evidence in southern areas[b]	Varying and inconsistent trends[a]	Inconsistent signals[b]
West Coast South America WSA, 9	Spatially varying trends (increases in hot days in some areas, decreases in others)[a]	Hot days *likely* to increase (cool days *likely* to decrease)[b]	Decrease in many areas, increase in a few areas[a]	Increases in tropics[b] *Low confidence* in extratropics[b]	Varying and inconsistent trends[a]	Decrease in consecutive dry days in the tropics, and increase in the extratropics[b] Increase in consecutive dry days and soil moisture in southwest South America[b]
North Asia NAS, 18	*Likely* increases in hot days (decreases in cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Increase in some regions, but spatial variation[a]	*Likely* increase in heavy precipitation for most regions[b]	Spatially varying trends[a]	Inconsistent signal of change[b]
Central Asia CAS, 20	*Likely* increases in hot days (decreases in cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Spatially varying trends[a]	Inconsistent signal in models[b]	Spatially varying trends[a]	Inconsistent signal of change[b]
East Asia EAS, 22	*Likely* increases in hot days (decreases in cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Spatially varying trends[a]	Increases in heavy precipitation across the region[b]	Tendency for increased dryness[a]	Inconsistent signal of change[b]
Southeast Asia SEA, 24	Increases in hot days (decreases in cool days) for northern areas[a] Insufficient evidence for Malay Archipelago[a]	*Likely* increase in hot days (decrease in cool days)[b]	Spatially varying trends, partial lack of evidence[a]	Increases in most metrics over most (especially non-continental) regions. One metric shows inconsistent signals of change.[b]	Spatially varying trends[a]	Inconsistent signal of change[b]
South Asia SAS, 23	Increase in hot days (decrease in cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Mixed signal in India[a]	More frequent and intense heavy precipitation days over parts of South Asia. Either no change or some consistent increases in other metrics[b]	Inconsistent signal for different studies and indices[a]	Inconsistent signal of change[b]
West Asia WAS, 19	*Very likely* increase in hot days (decrease in cool days *more likely than not*)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Decrease in heavy precipitation events[a]	Inconsistent signal of change[b]	Lack of studies, mixed results[a]	Inconsistent signal of change[b]
Tibetan Plateau TIB, 21	*Likely* increase in hot days (decrease in cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Insufficient evidence[a]	Increase in heavy precipitation[b]	Insufficient evidence. Tendency to decreased dryness[a]	Inconsistent signal of change[b]
North Australia NAU, 25	*Likely* increase in hot days (decrease in cool days). Weaker trends in northwest[a]	*Very likely* increase in hot days (decrease in cool days)[b]	Spatially varying trends, which mostly reflect changes in mean rainfall[e]	Increase in most regions in the intensity of extreme (i.e., current 20-year return period) heavy rainfall events[e]	No significant change in drought occurrence over Australia (defined using rainfall anomalies)[e]	Inconsistent signal[b]

Continued next page →

TS

Table TS.6 (continued)

Region/ region code	Trends in daytime temperature extremes (frequency of hot and cool days)		Trends in heavy precipitation (rain, snow)		Trends in dryness and drought	
	Observed	Projected	Observed	Projected	Observed	Projected
South Australia/ New Zealand SAU, 26	*Very likely* increase in hot days (decrease in cool days)[a]	*Very likely* increase in hot days (decrease in cool days)[b]	Spatially varying trends in southern Australia, which mostly reflect changes in mean rainfall[e] Spatially varying trends in New Zealand, which mostly reflect changes in mean rainfall[e]	Increase in most regions in the intensity of extreme (i.e., current 20-year return period) heavy rainfall events[e]	No significant change in drought occurrence over Australia (defined using rainfall anomalies)[e] No trend in drought occurrence over New Zealand (defined using a soil–water balance model) since 1972[e]	Increase in drought frequency in southern Australia, and in many regions of New Zealand[e]

negatively impact island communities and livelihoods, given the dependence of island communities on coral reef ecosystems for coastal protection, subsistence fisheries, and tourism. [29.3 to 29.5, 29.9, 30.5, Figure 29-1, Table 29-3, Box CC-CR]

***The Ocean*. Warming will increase risks to ocean ecosystems (*high confidence*).** Coral reefs within coastal boundary systems, semi-enclosed seas, and subtropical gyres are rapidly declining as a result of local non-climatic stressors (i.e., coastal pollution, overexploitation) and climate change. Projected increases in mass coral bleaching and mortality will alter or eliminate ecosystems, increasing risks to coastal livelihoods and food security (*medium* to *high confidence*). An analysis of the CMIP5 ensemble projects loss of coral reefs from most sites globally to be *very likely* by 2050 under mid to high rates of ocean warming. Reducing non-climatic stressors represents an opportunity to strengthen ecological resilience. The highly productive high-latitude spring bloom systems in the northeastern Atlantic are responding to warming (*medium evidence*, *high agreement*), with the greatest changes being observed since the late 1970s in the phenology, distribution, and abundance of plankton assemblages, and the reorganization of fish assemblages, with a range of consequences for fisheries (*high confidence*). Projected warming increases the likelihood of greater thermal stratification in some regions, which can lead to reduced O_2 ventilation and encourage the formation of hypoxic zones, especially in the Baltic and Black Seas (*medium confidence*). Changing surface winds and waves, sea level, and storm intensity will increase the vulnerability of ocean-based industries such as shipping, energy, and mineral extraction. New opportunities as well as international issues over access to resources and vulnerability may accompany warming waters particularly at high latitudes. [5.3, 5.4, 6.4, 28.2, 28.3, 30.3, 30.5, 30.6, Table 30-1, Figures 30-4 and 30-10, Boxes 6-1, CC-CR, and CC-MB]

Understanding of extreme events and their interactions with climate change is particularly important for managing risks in a regional context. Table TS.6 provides a summary of observed and projected trends in some types of temperature and precipitation extremes.

C: MANAGING FUTURE RISKS AND BUILDING RESILIENCE

Managing the risks of climate change involves adaptation and mitigation decisions with implications for future generations, economies, and environments. Figure TS.12 provides an overview of responses for addressing risk related to climate change.

Starting with principles for effective adaptation, this section evaluates the ways that interlinked human and natural systems can build resilience through adaptation, mitigation, and sustainable development. It describes understanding of climate-resilient pathways, of incremental versus transformational changes, and of limits to adaptation, and it considers co-benefits, synergies, and trade-offs among mitigation, adaptation, and development.

C-1. Principles for Effective Adaptation

The report assesses a wide variety of approaches for reducing and managing risks and building resilience. Strategies and approaches to climate change adaptation include efforts to decrease vulnerability or exposure and/or increase resilience or adaptive capacity. Mitigation is assessed in the WGIII AR5. Specific examples of responses to climate change are presented in Table TS.7.

Adaptation is place- and context-specific, with no single approach for reducing risks appropriate across all settings (*high confidence*). Effective risk reduction and adaptation strategies consider the dynamics of vulnerability and exposure and their linkages with socioeconomic processes, sustainable development, and climate change. [2.1, 8.3, 8.4, 13.1, 13.3, 13.4, 15.2, 15.3, 15.5, 16.2, 16.3, 16.5, 17.2, 17.4, 19.6, 21.3, 22.4, 26.8, 26.9, 29.6, 29.8]

Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments (*high confidence*). National governments can coordinate adaptation efforts of local and subnational governments, for example by protecting vulnerable groups, by supporting economic diversification, and by providing information, policy and legal frameworks, and financial support (*robust evidence*, *high agreement*). Local government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households, and civil society and in managing risk information and financing (*medium evidence*, *high agreement*). [2.1 to 2.4, 3.6, 5.5, 8.3, 8.4, 9.3, 9.4, 14.2, 15.2, 15.3, 15.5, 16.2 to 16.5, 17.2, 17.3, 22.4, 24.4, 25.4, 26.8, 26.9, 30.7, Tables 21-1, 21-5, and 21-6, Box 16-2]

A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*). Strategies include actions with co-benefits for other objectives. Available strategies and actions can increase resilience across a range of possible future climates while helping to improve human health, livelihoods, social and economic well-being, and environmental quality. Examples of adaptation strategies that also strengthen livelihoods, enhance development, and reduce poverty include improved social protection, improved water and land governance, enhanced water storage and services, greater involvement in planning, and elevated attention to urban and peri-urban areas heavily affected by migration of poor people. See Table TS.7. [3.6, 8.3, 9.4, 14.3, 15.2, 15.3, 17.2, 20.4, 20.6, 22.4, 24.4, 24.5, 25.4, 25.10, 27.3 to 27.5, 29.6, Boxes 25-2 and 25-6]

Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives, and risk perceptions (*high confidence*). Recognition of diverse interests, circumstances, social-cultural contexts, and expectations can

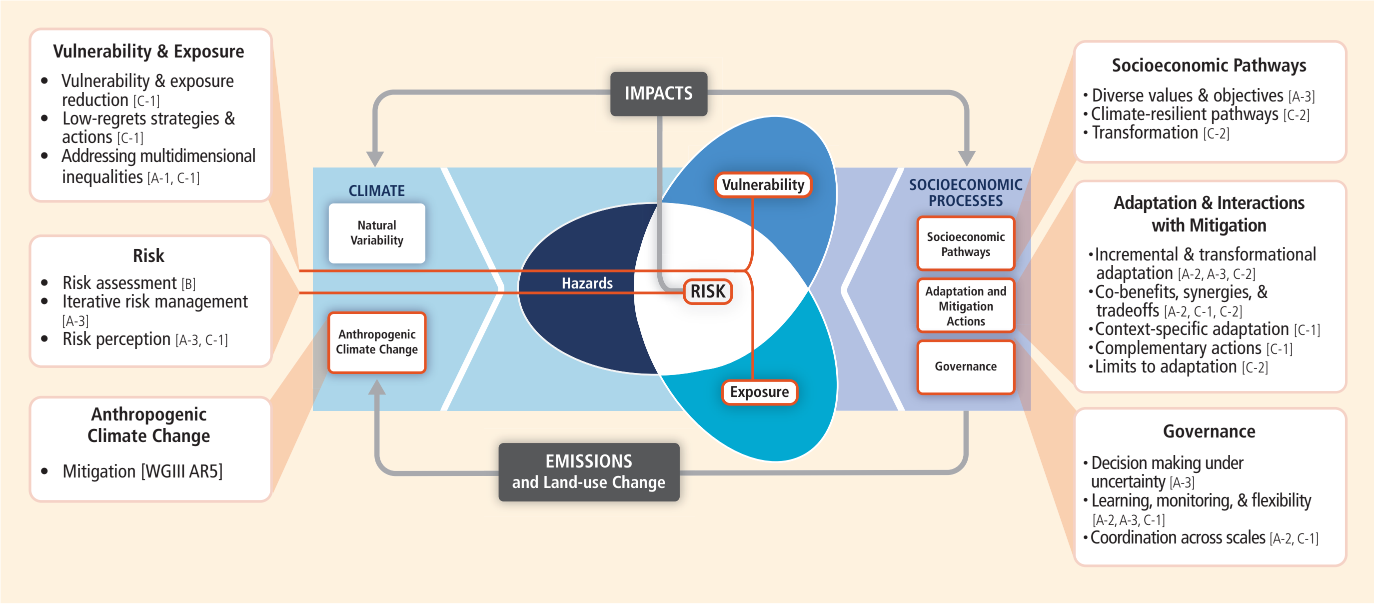


Figure TS.12 | The solution space. Core concepts of the WGII AR5, illustrating overlapping entry points and approaches, as well as key considerations, in managing risks related to climate change, as assessed in the report and presented throughout this summary. Bracketed references indicate sections of the summary with corresponding assessment findings.

Table TS.7 | Approaches for managing the risks of climate change. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Mitigation is considered essential for managing the risks of climate change. It is not addressed in this table as mitigation is the focus of WGIII AR5. Examples are presented in no specific order and can be relevant to more than one category. [14.2, 14.3, Table 14-1]

Overlapping Approaches	Category	Examples	Chapter Reference(s)
Vulnerability & Exposure Reduction through development, planning, & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.	8.3, 9.3, 13.1 to 13.3, 14.2, 14.3, 22.4
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.	8.3, 8.4, 9.3, 13.1 to 13.3
	Livelihood security	Income, asset, & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.	7.5, 9.4, 13.1 to 13.3, 22.3, 22.4, 23.4, 26.5, 27.3, 29.6, Table SM24-7
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.	8.2 to 8.4, 11.7, 14.3, 15.4, 22.4, 24.4, 26.6, 28.4, Table 3-3, Box 25-1
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.	4.3, 4.4, 8.3, 22.4, Table 3-3, Boxes 4-3, 8-2, 15-1, 25-8, 25-9, & CC-EA
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure, & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.	4.4, 8.1 to 8.4, 22.4, 23.7, 23.8, 27.3, Box 25-8
Adaptation including incremental & transformational adjustments	Structural/physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.	3.5, 3.6, 5.5, 8.2, 8.3, 10.2, 11.7, 23.3, 24.4, 25.7, 26.3, 26.8, Boxes 15-1, 25-1, 25-2, & 25-8
		Technological options: New crop & animal varieties; Indigenous, traditional, & local knowledge, technologies, & methods; Efficient irrigation; Water-saving technologies; Desalinization; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer, & diffusion.	7.5, 8.3, 9.4, 10.3, 15.4, 22.4, 24.4, 26.3, 26.5, 27.3, 28.2, 28.4, 29.6, 29.7, Tables 3-3 & 15-1, Boxes 20-5 & 25-2
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks, & other *ex situ* conservation; Community-based natural resource management.	4.4, 5.5, 6.4, 8.3, 9.4, 11.7, 15.4, 22.4, 23.6, 23.7, 24.4, 25.6, 27.3, 28.2, 29.7, 30.6, Boxes 15-1, 22-2, 25-9, 26-2, & CC-EA
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.	3.5, 3.6, 8.3, 9.3, 11.7, 11.9, 22.4, 29.6, Box 13-2
	Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.	8.3, 8.4, 9.4, 10.7, 11.7, 13.3, 15.4, 17.5, 22.4, 26.7, 27.6, 29.6, Box 25-7
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.	4.4, 8.3, 9.3, 10.5, 10.7, 15.2, 15.4, 17.5, 22.4, 23.4, 23.7, 24.4, 25.4, 26.3, 27.3, 30.6, Table 25-2, Box CC-CR
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.	2.4, 3.6, 4.4, 5.5, 6.4, 7.5, 8.3, 11.7, 15.2 to 15.5, 22.4, 23.7, 25.4, 25.8, 26.8, 26.9, 27.3, 27.4, 29.6, Tables 9-2 & 17-1, Boxes 25-1, 25-2, & 25-9
	Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional, & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.	8.3, 8.4, 9.4, 11.7, 12.3, 15.2 to 15.4, 22.4, 25.4, 28.4, 29.6, Tables 15-1 & 25-2
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.	2.4, 5.5, 8.3, 8.4, 9.4, 11.7, 15.2 to 15.4, 22.4, 23.5, 24.4, 25.8, 26.6, 26.8, 27.3, 28.2, 28.5, 30.6, Table 25-2, Box 26-3
		Behavioral options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.	5.5, 7.5, 9.4, 12.4, 22.3, 22.4, 23.4, 23.7, 25.7, 26.5, 27.3, 29.6, Table SM24-7, Box 25-5
Transformation	Spheres of change	***Practical***: Social & technical innovations, behavioral shifts, or institutional & managerial changes that produce substantial shifts in outcomes.	8.3, 17.3, 20.5, Box 25-5
		Political: Political, social, cultural, & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation, & sustainable development.	14.2, 14.3, 20.5, 25.4, 30.7, Table 14-1
		Personal: Individual & collective assumptions, beliefs, values, & worldviews influencing climate-change responses.	14.2, 14.3, 20.5, 25.4, Table 14-1

benefit decision-making processes. Awareness that climate change may exceed the adaptive capacity of some people and ecosystems may have ethical implications for mitigation decisions and investments. Economic analysis of adaptation is moving away from a unique emphasis on efficiency, market solutions, and benefit/cost analysis to include consideration of non-monetary and non-market measures, risks, inequities, behavioral biases, barriers and limits, and ancillary benefits and costs. [2.2 to 2.4, 9.4, 12.3, 13.2, 15.2, 16.2 to 16.4, 16.6, 16.7, 17.2, 17.3, 21.3, 22.4, 24.4, 24.6, 25.4, 25.8, 26.9, 28.2, 28.4, Table 15-1, Boxes 16-1, 16-4, and 25-7]

Indigenous, local, and traditional knowledge systems and practices, including indigenous peoples' holistic view of community and environment, are a major resource for adapting to climate change (*robust evidence*, *high agreement*). Natural resource dependent communities, including indigenous peoples, have a long history of adapting to highly variable and changing social and ecological conditions. But the salience of indigenous, local, and traditional knowledge will be challenged by climate change impacts. Such forms of knowledge have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge with existing practices increases the effectiveness of adaptation. [9.4, 12.3, 15.2, 22.4, 24.4, 24.6, 25.8, 28.2, 28.4, Table 15-1]

Decision support is most effective when it is sensitive to context and the diversity of decision types, decision processes, and constituencies (*robust evidence*, *high agreement*). Organizations bridging science and decision making, including climate services, play an important role in the communication, transfer, and development of climate-related knowledge, including translation, engagement, and knowledge exchange (*medium evidence*, *high agreement*). [2.1 to 2.4, 8.4, 14.4, 16.2, 16.3, 16.5, 21.2, 21.3, 21.5, 22.4, Box 9-4]

Integration of adaptation into planning and decision making can promote synergies with development and disaster risk reduction (*high confidence*). Such mainstreaming embeds climate-sensitive thinking in existing and new institutions and organizations. Adaptation can generate larger benefits when connected with development activities and disaster risk reduction (*medium confidence*). [8.3, 9.3, 14.2, 14.6, 15.3, 15.4, 17.2, 20.2, 20.3, 22.4, 24.5, 29.6, Box CC-UR]

Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts (*medium confidence*). Instruments include public–private finance partnerships, loans, payments for environmental services, improved resource pricing, charges and subsidies, norms and regulations, and risk sharing and transfer mechanisms. Risk financing mechanisms in the public and private sector, such as insurance and risk pools, can contribute to increasing resilience, but without attention to major design challenges, they can also provide disincentives, cause market failure, and decrease equity. Governments often play key roles as regulators, providers, or insurers of last resort. [10.7, 10.9, 13.3, 17.4, 17.5, Box 25-7]

Constraints can interact to impede adaptation planning and implementation (*high confidence*). Common constraints on implementation arise from the following: limited financial and human resources; limited integration or coordination of governance; uncertainties about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Another constraint includes insufficient research, monitoring, and observation and the finance to maintain them. Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes. [3.6, 4.4, 5.5, 8.4, 9.4, 13.2, 13.3, 14.2, 14.5, 15.2, 15.3, 15.5, 16.2, 16.3, 16.5, 17.2, 17.3, 22.4, 23.7, 24.5, 25.4, 25.10, 26.8, 26.9, 30.6, Table 16-3, Boxes 16-1 and 16-3]

Poor planning, overemphasizing short-term outcomes, or failing to sufficiently anticipate consequences can result in maladaptation (*medium evidence*, *high agreement*). Maladaptation can increase the vulnerability or exposure of the target group in the future, or the vulnerability of other people, places, or sectors. Narrow focus on quantifiable costs and benefits can bias decisions against the poor, against ecosystems, and against those in the future whose values can be excluded or are understated. Some near-term responses to increasing risks related to climate change may also limit future choices. For example, enhanced protection of exposed assets can lock in dependence on further protection measures. [5.5, 8.4, 14.6, 15.5, 16.3, 17.2, 17.3, 20.2, 22.4, 24.4, 25.10, 26.8, Table 14-4, Box 25-1]

Limited evidence indicates a gap between global adaptation needs and funds available for adaptation (*medium confidence*). There is a need for a better assessment of global adaptation costs, funding, and investment. Studies estimating the global cost of adaptation are characterized by shortcomings in data, methods, and coverage (*high confidence*). [14.2, 17.4, Tables 17-2 and 17-3]

C-2. Climate-resilient Pathways and Transformation

Climate-resilient pathways are sustainable-development trajectories that combine adaptation and mitigation to reduce climate change and its impacts. They include iterative processes to ensure that effective risk management can be implemented and sustained. See Figure TS.13. [2.5, 20.3, 20.4]

Prospects for climate-resilient pathways for sustainable development are related fundamentally to what the world accomplishes with climate-change mitigation (*high confidence*). Since mitigation reduces the rate as well as the magnitude of warming, it also increases the time available for adaptation to a particular level of climate change, potentially by several decades. Delaying mitigation actions may reduce options for climate-resilient pathways in the future. [1.1, 19.7, 20.2, 20.3, 20.6, Figure 1-5]

Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). See Box TS.8. Limits to adaptation occur when adaptive actions to avoid intolerable risks for an actor's objectives or for the needs of a system are not possible or are not currently available. Value-based judgments

TS

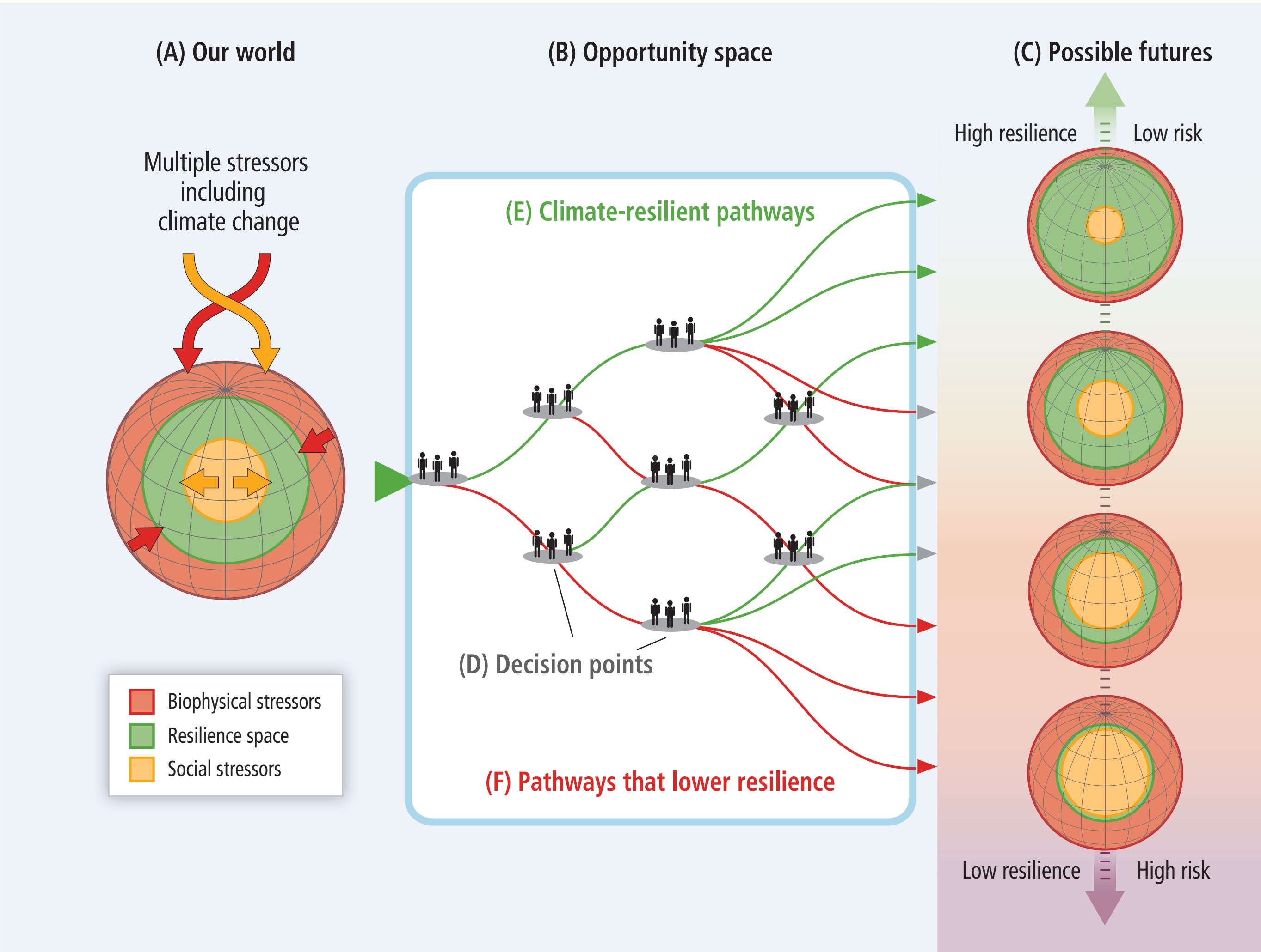


Figure TS.13 | Opportunity space and climate-resilient pathways. (A) Our world [Sections A-1 and B-1] is threatened by multiple stressors that impinge on resilience from many directions, represented here simply as biophysical and social stressors. Stressors include climate change, climate variability, land-use change, degradation of ecosystems, poverty and inequality, and cultural factors. (B) Opportunity space [Sections A-2, A-3, B-2, C-1, and C-2] refers to decision points and pathways that lead to a range of (C) possible futures [Sections C and B-3] with differing levels of resilience and risk. (D) Decision points result in actions or failures-to-act throughout the opportunity space, and together they constitute the process of managing or failing to manage risks related to climate change. (E) Climate-resilient pathways (in green) within the opportunity space lead to a more resilient world through adaptive learning, increasing scientific knowledge, effective adaptation and mitigation measures, and other choices that reduce risks. (F) Pathways that lower resilience (in red) can involve insufficient mitigation, maladaptation, failure to learn and use knowledge, and other actions that lower resilience; and they can be irreversible in terms of possible futures. [Figure 1-5]

of what constitutes an intolerable risk may differ. Limits to adaptation emerge from the interaction among climate change and biophysical and/or socioeconomic constraints. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if limits to adaptation are exceeded. In some parts of the world, insufficient responses to emerging impacts are already eroding the basis for sustainable development. [1.1, 11.8, 13.4, 16.2 to 16.7, 17.2, 20.2, 20.3, 20.5, 20.6, 25.10, 26.5, Boxes 16-1, 16-3, and 16-4]

Transformations in economic, social, technological, and political decisions and actions can enable climate-resilient pathways (*high confidence*). Specific examples are presented in Table TS.7. See also Box TS.8. Strategies and actions can be pursued now that will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being, and responsible environmental management. Transformations in response to climate change may involve, for example, introduction of new technologies or practices, formation of new structures or systems of governance, or shifts in the types or locations of activities. The scale and magnitude of transformational adaptations depend on mitigation and on development processes. Transformational adaptation is an important consideration for decisions involving long life- or lead-times, and it can be a response to adaptation limits. At the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with its national circumstances and priorities. Transformations to sustainability are considered to benefit from iterative learning, deliberative processes, and innovation. Societal debates about many aspects of transformation may place new and increased demands on governance structures. [1.1, 2.1, 2.5, 8.4, 14.1, 14.3, 16.2 to 16.7, 20.5, 22.4, 25.4, 25.10, Figure 1-5, Boxes 16-1 and 16-4]

Examples of Co-benefits, Synergies, and Trade-offs among Adaptation, Mitigation, and Sustainable Development

Significant co-benefits, synergies, and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions (*very high confidence*). Illustrative examples include the following.

- Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections among water, energy, land use, and biodiversity, but tools to understand and manage these interactions remain limited (*very high confidence*). See Box TS.9. Widespread transformation of terrestrial ecosystems in order to mitigate climate change, such as carbon sequestration through planting fast-growing tree species into ecosystems where they did not previously occur, or the conversion of previously uncultivated or non-degraded land to bioenergy plantations, can lead to negative impacts on ecosystems and biodiversity (*high confidence*). [3.7, 4.2 to 4.4, 22.6, 24.6, 25.7, 25.9, 27.3, Boxes 25-10 and CC-WE]
- Climate policies such as increasing energy supply from renewable resources, encouraging bioenergy crop cultivation, or facilitating payments under REDD+ will affect some rural areas both positively (e.g., increasing employment opportunities) and negatively (e.g., land use changes, increasing scarcity of natural capital) (*medium confidence*). These secondary impacts, and trade-offs between mitigation and adaptation in rural areas, have implications for governance, including benefits of promoting participation of rural stakeholders. Mitigation policies with social co-benefits expected in their design, such as CDM and REDD+, have had limited or no effect in terms of poverty alleviation and sustainable development

Box TS.8 | Adaptation Limits and Transformation

Adaptation can expand the capacity of natural and human systems to cope with a changing climate. Risk-based decision making can be used to assess potential limits to adaptation. Limits to adaptation occur when adaptive actions to avoid intolerable risks for an actor's objectives or for the needs of a system are not possible or are not currently available. Limits to adaptation are context-specific and closely linked to cultural norms and societal values. Value-based judgments of what constitutes an intolerable risk may differ among actors, but understandings of limits to adaptation can be informed by historical experiences, or by anticipation of impacts, vulnerability, and adaptation associated with different scenarios of climate change. The greater the magnitude or rate of climate change, the greater the likelihood that adaptation will encounter limits. [16.2 to 16.4, 20.5, 20.6, 22.4, 25.4, 25.10, Box 16-2]

Limits to adaptation may be influenced by the subjective values of societal actors, which can affect both the perceived need for adaptation and the perceived appropriateness of specific policies and measures. While limits imply that intolerable risks and the increased potential for losses and damages can no longer be avoided, the dynamics of social and ecological systems mean that there are both "soft" and "hard" limits to adaptation. For "soft" limits, there are opportunities in the future to alter limits and reduce risks, for example, through the emergence of new technologies or changes in laws, institutions, or values. In contrast, "hard" limits are those where there are no reasonable prospects for avoiding intolerable risks. Recent studies on tipping points, key vulnerabilities, and planetary boundaries provide some insights on the behavior of complex systems. [16.2 to 16.7, 25.10]

In cases where the limits to adaptation have been surpassed, losses and damage may increase and the objectives of some actors may no longer be achievable. There may be a need for transformational adaptation to change fundamental attributes of a system in response to actual or expected impacts of climate change. It may involve adaptations at a greater scale or intensity than previously experienced, adaptations that are new to a region or system, or adaptations that transform places or lead to a shift in the types or locations of activities. [16.2 to 16.4, 20.3, 20.5, 22.4, 25.10, Boxes 25-1 and 25-9]

The existence of limits to adaptation suggests transformational change may be a requirement for sustainable development in a changing climate—that is, not only for adapting to the impacts of climate change, but for altering the systems and structures, economic and social relations, and beliefs and behaviors that contribute to climate change and social vulnerability. However, just as there are ethical implications associated with some adaptation options, there are also legitimate concerns about the equity and ethical dimensions of transformation. Societal debates over risks from forced and reactive transformations as opposed to deliberate transitions to sustainability may place new and increased demands on governance structures at multiple levels to reconcile conflicting goals and visions for the future. [1.1, 16.2 to 16.7, 20.5, 25.10] (*medium confidence*). Mitigation efforts focused on land acquisition for biofuel production show preliminary negative impacts for the poor in many developing countries, and particularly for indigenous people and (women) smallholders. [9.3, 13.3, 22.6]

- Mangrove, seagrass, and salt marsh ecosystems offer important carbon storage and sequestration opportunities (*limited evidence*, *medium agreement*), in addition to ecosystem goods and services such as protection against coastal erosion and storm damage and maintenance of habitats for fisheries species. For ocean-related mitigation and adaptation in the context of anthropogenic ocean warming and acidification, international frameworks offer opportunities to solve problems collectively, for example, managing fisheries across national borders and responding to extreme events. [5.4, 25.6, 30.6, 30.7]

Table TS.8 | Illustrative examples of intra-regional interactions among adaptation, mitigation, and sustainable development.

Green infrastructure and green roofs	
Objectives	Storm water management, adaptation to increasing temperatures, reduced energy use, urban regeneration
Relevant sectors	Infrastructure, energy use, water management
Overview	Benefits of green infrastructure and roofs can include reduction of storm water runoff and the urban heat island effect, improved energy performance of buildings, reduced noise and air pollution, health improvements, better amenity value, increased property values, improved biodiversity, and inward investment. Trade-offs can result between higher urban density to improve energy efficiency and open space for green infrastructure. [8.3.3, 11.7.4, 23.7.4, 24.6, Tables 11-3 and 25-5]
Examples with interactions	**London:** The Green Grid for East London seeks to create interlinked and multi-purpose open spaces to support regeneration of the area. It aims to connect people and places, to absorb and store water, to cool the vicinity, and to provide a diverse mosaic of habitats for wildlife. [8.3.3] **New York:** In preparation for more intense storms, New York is using green infrastructure to capture rainwater before it can flood the combined sewer system, implementing green roofs, and elevating boilers and other equipment above ground. [8.3.3, 26.3.3, 26.8.4] **Singapore:** Singapore has used several anticipatory plans and projects to enhance green infrastructure, including its Streetscape Greenery Master Plan, constructed wetlands or drains, and community gardens. Under its Skyrise Greenery project, Singapore has provided subsidies and handbooks for rooftop and wall greening initiatives. [8.3.3] **Durban:** Ecosystem-based adaptation is part of Durban's climate change adaptation strategy. The approach seeks a more detailed understanding of the ecology of indigenous ecosystems and ways in which biodiversity and ecosystem services can reduce vulnerability of ecosystems and people. Examples include the Community Reforestation Programme, in which communities produce indigenous seedlings used in the planting and managing of restored forest areas. Development of ecosystem-based adaptation in Durban has demonstrated needs for local knowledge and data and the benefits of enhancing existing protected areas, land-use practices, and local initiatives contributing to jobs, business, and skill development. [8.3.3, Box 8-2]
Water management	
Primary objective	Water resource management given multiple stressors in a changing climate
Relevant sectors	Water use, energy production and use, biodiversity, carbon sequestration, biofuel production, food production
Overview	Water management in the context of climate change can encompass ecosystem-based approaches (e.g., watershed management or restoration, flood regulation services, and reduction of erosion or siltation), supply-side approaches (e.g., dams, reservoirs, groundwater pumping and recharge, and water capture), and demand-side approaches (e.g., increased use efficiency through water recycling, infrastructure upgrades, water-sensitive design, or more efficient allocation). Water may require significant amounts of energy for lifting, transport, distribution, and treatment. [3.7.2, 26.3, Tables 9-8 and 25-5, Boxes CC-EA and CC-WE]
Examples with interactions	**New York:** New York has a well-established program to protect and enhance its water supply through watershed protection. The Watershed Protection Program includes city ownership of land that remains undeveloped and coordination with landowners and communities to balance water-quality protection, local economic development, and improved wastewater treatment. The city government indicates it is the most cost-effective choice for New York given the costs and environmental impacts of a filtration plant. [8.3.3, Box 26-3] **Cape Town:** Facing challenges in ensuring future supplies, Cape Town responded by commissioning water management studies, which identified the need to incorporate climate change, as well as population and economic growth, in planning. During the 2005 drought, local authorities increased water tariffs to promote efficient water usage. Additional measures may include water restrictions, reuse of gray water, consumer education, or technological solutions such as low-flow systems or dual flush toilets. [8.3.3] **Capital cities in Australia:** Many Australian capital cities are reducing reliance on catchment runoff and groundwater—water resources most sensitive to climate change and drought—and are diversifying supplies through desalination plants, water reuse including sewage and storm water recycling, and integrated water cycle management that considers climate change impacts. Demand is being reduced through water conservation and water-sensitive urban design and, during severe shortfalls, through implementation of restrictions. The water augmentation program in Melbourne includes a desalination plant. Trade-offs beyond energy intensiveness have been noted, such as damage to sites significant to aboriginal communities and higher water costs that will disproportionately affect poorer households. [14.6.2, Tables 25-6 and 25-7, Box 25-2]
Payment for environmental services and green fiscal policies	
Primary objective	Management incorporating the costs of environmental externalities and the benefits of ecosystem services
Relevant sectors	Biodiversity, ecosystem services
Overview	Payment for environmental services (PES) is a market-based approach that aims to protect natural areas, and associated livelihoods and environmental services, by developing financial incentives for preservation. Mitigation-focused PES schemes are common, and there is emerging evidence of adaptation-focused PES schemes. Successful PES approaches can be difficult to design for services that are hard to define or quantify. [17.5.2, 27.6.2]
Examples with interactions	**Central and South America:** A variety of PES schemes have been implemented in Central and South America. For example, national-level programs have operated in Costa Rica and Guatemala since 1997 and in Ecuador since 2008. Examples to date have shown that PES can finance conservation, ecosystem restoration and reforestation, better land-use practices, mitigation, and more recently adaptation. Uniform payments for beneficiaries can be inefficient if, for example, recipients that promote greater environmental gains receive only the prevailing payment. [17.5.2, 27.3.2, 27.6.2, Table 27-8] **Brazil:** Municipal funding in Brazil tied to ecosystem-management quality is a form of revenue transfer important to funding local adaptation actions. State governments collect a value-added tax redistributed among municipalities, and some states allocate revenues in part based on municipality area set aside for protection. This mechanism has helped improve environmental management and increased creation of protected areas. It benefits relations between protected areas and surrounding inhabitants, as the areas can be perceived as opportunities for revenue generation rather than as obstacles to development. The approach builds on existing institutions and administrative procedures and thus has low transaction costs. [8.4.3, Box 8-4]

Continued next page →

Table TS.8 (continued)

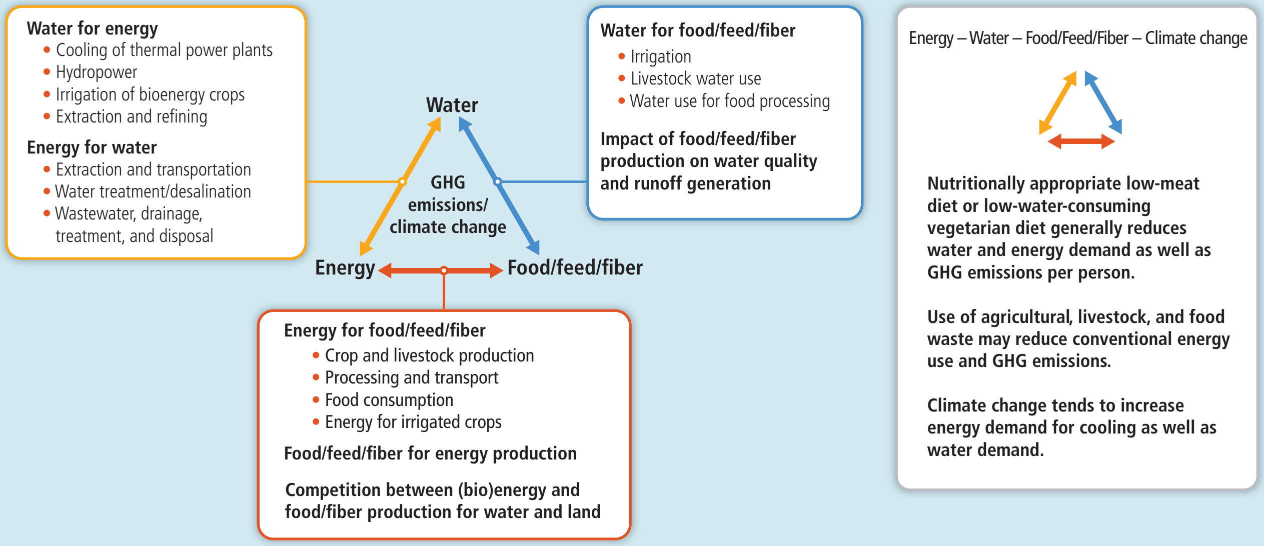
Renewable energy	
Primary objective	Renewable energy production and reduction of emissions
Relevant sectors	Biodiversity, agriculture, food security
Overview	Renewable energy production can require significant land areas and water resources, creating the potential for both positive and negative interactions between mitigation policies and land management. [4.4.4, 13.3.1, 19.3.2, 19.4.1, Box CC-WE]
Examples with interactions	**Central and South America:** Renewable resources, especially hydroelectric power and biofuels, account for substantial fractions of energy production in countries such as Brazil. Where bioenergy crops compete for land with food crops, substantial trade-offs can exist. Land-use change to produce bioenergy can affect food crops, biodiversity, and ecosystem services. Lignocellulosic feedstocks, such as sugarcane second-generation technologies, do not compete with food. [19.3.2, 27.3.6, 27.6.1, Table 27-6] **Australia and New Zealand:** Mandatory renewable energy targets and incentives to increase carbon storage support increased biofuel production and increased biological carbon sequestration, with impacts on biodiversity depending on implementation. Benefits can include reduced erosion, additional habitat, and enhanced connectivity, with risks or lost opportunities associated with large-scale monocultures especially if replacing more diverse landscapes. Large-scale land cover changes can affect catchment yields and regional climate in complex ways. New crops such as oil mallees or other eucalypts may provide multiple benefits, especially in marginal areas, displacing fossil fuels or sequestering carbon, generating income for landholders (essential oils, charcoal, bio-char, biofuels), and providing ecosystem services. [Table 25-7, Box 25-10]
Disaster risk reduction and adaptation to climate extremes	
Primary objective	Increasing resilience to extreme weather events in a changing climate
Relevant sectors	Infrastructure, energy use, spatial planning
Overview	Synergies and tradeoffs among sustainable development, adaptation, and mitigation occur in preparing for and responding to climate extremes and disasters. [13.2 to 13.4, 20.3, 20.4]
Examples with interactions	**Philippines:** The Homeless People's Federation of the Philippines developed responses following disasters, including community-rooted data gathering (e.g., assessing destruction and victims' immediate needs); trust and contact building; savings support; community-organization registration; and identification of needed interventions (e.g., building-materials loans). Community surveys mapped inhabitants especially at risk in informal settlements, raising risk-awareness among the inhabitants and increasing community engagement in planning risk reduction and early warning systems. [8.3.2, 8.4.2] **London:** Within London, built form and other dwelling characteristics can have a stronger influence on indoor temperatures during heat waves than the urban heat island effect, and utilizing shade, thermal mass, ventilation control, and other passive-design features are effective adaptation options. Passive housing designs enhance natural ventilation and improve insulation, while also reducing household emissions. For example, in London the Beddington Zero Energy Development was designed to reduce or eliminate energy demand for heating, cooling, and ventilation for much of the year. [8.3.3, 11.7.4] **United States:** In the United States, post-disaster funds for loss reduction are added to funds provided for disaster recovery. They can be used, for instance, to buy out properties that have experienced repetitive flood losses and relocate residents to safer locations, to elevate structures, to assist communities with purchasing property and altering land-use patterns in flood-prone areas, and to undertake other activities designed to lessen the impacts of future disasters. [14.3.3]

- Geoengineering approaches involving manipulation of the ocean to ameliorate climate change (such as nutrient fertilization, binding of CO_2 by enhanced alkalinity, or direct CO_2 injection into the deep ocean) have very large environmental and associated socioeconomic consequences (*high confidence*). Alternative methods focusing on solar radiation management (SRM) leave ocean acidification unabated as they cannot mitigate rising atmospheric CO_2 emissions. [6.4]
- Some agricultural practices can reduce emissions and also increase resilience of crops to temperature and rainfall variability (*high confidence*). [23.8, Table 25-7]
- Many solutions for reducing energy and water consumption in urban areas with co-benefits for climate change adaptation (e.g., greening cities and recycling water) are already being implemented (*high confidence*). Transport systems promoting active transport and reduced motorized-vehicle use can improve air quality and increase physical activity (*medium confidence*). [11.9, 23.8, 24.4, 26.3, 26.8, Boxes 25-2 and 25-9]
- Improved energy efficiency and cleaner energy sources can lead to reduced emissions of health-damaging climate-altering air pollutants (*very high confidence*). [11.9, 23.8]
- In Africa, experience in implementing integrated adaptation–mitigation responses that leverage developmental benefits encompasses some participation of farmers and local communities in carbon offset systems and increased use of agroforestry and farmer-assisted tree regeneration (*high confidence*). [22.4, 22.6]
- In Asia, development of sustainable cities with fewer fossil-fuel-driven vehicles and with more trees and greenery would have a number of co-benefits, including improved public health (*high confidence*). [24.4 to 24.7]
- In Australasia, transboundary effects from climate change impacts and responses outside Australasia have the potential to outweigh some of the direct impacts within the region, particularly economic impacts on trade-intensive sectors such as agriculture (*medium confidence*) and tourism (*limited evidence*, *high agreement*), but they remain among the least-explored issues. [25.7, 25.9, Box 25-10]
- In North America, policies addressing local concerns (e.g., air pollution, housing for the poor, declines in agricultural production) can be adapted at low or no cost to fulfill adaptation, mitigation, and sustainability goals (*medium confidence*). [26.9]
- In Central and South America, biomass-based renewable energy can impact land use change and deforestation, and could be affected by climate change (*medium confidence*). The expansion of sugarcane, soy, and oil palm may have some effect on land use, leading to deforestation in parts of the Amazon and Central America, among other sub-regions, and to loss of employment in some countries. [27.3]
- For small islands, energy supply and use, tourism infrastructure and activities, and coastal wetlands offer opportunities for adaptation–mitigation synergies (*medium confidence*). [29.6 to 29.8]

Table TS.8 provides further specific examples of interactions among adaptation, mitigation, and sustainable development to complement the assessment findings above.

Box TS.9 | The Water–Energy–Food Nexus

Water, energy, and food/feed/fiber are linked through numerous interactive pathways affected by a changing climate (Box TS.9 Figure 1). [Box CC-WE] The depth and intensity of those linkages vary enormously among countries, regions, and production systems. Many energy sources require significant amounts of water and produce a large quantity of wastewater that requires energy for treatment. [3.7, 7.3, 10.2, 10.3, 22.3, 25.7, Box CC-WE] Food production, refrigeration, transport, and processing also require both energy and water. A major link between food and energy as related to climate change is the competition of bioenergy and food production for land and water, and the sensitivity of precipitation, temperature, and crop yields to climate change (*robust evidence*, *high agreement*). [7.3, Boxes 25-10 and CC-WE]



Box TS.9 Figure 1 | The water–energy–food nexus as related to climate change, with implications for both adaptation and mitigation strategies. [Figure WE-1, Box CC-WE]

Most energy production methods require significant amounts of water, either directly (e.g., crop-based energy sources and hydropower) or indirectly (e.g., cooling for thermal energy sources or other operations) (*robust evidence*, *high agreement*). [10.2, 10.3, 25.7, Box CC-WE] Water is required for mining, processing, and residue disposal of fossil fuels or their byproducts. [25.7] Water for energy currently ranges from a few percent in most developing countries to more than 50% of freshwater withdrawals in some developed countries, depending on the country. [Box CC-WE] Future water requirements will depend on electric demand growth, the portfolio of generation technologies, and water management options (*medium evidence*, *high agreement*). Future water availability for energy production will change due to climate change (*robust evidence*, *high agreement*). [3.4, 3.5, Box CC-WE]

Energy is also required to supply and treat water. Water may require significant amounts of energy for lifting (especially as aquifers continue to be depleted), transport, and distribution and for its treatment either to use it or to depollute it. Wastewater and even excess rainfall in cities requires energy to be treated or disposed. Some non-conventional water sources (wastewater or seawater) are often highly energy intensive. [Table 25-7, Box 25-2] Energy intensities per cubic meter of water vary by about a factor of 10 among different sources, for example, locally produced potable water from ground/surface water sources versus desalinated seawater. [Boxes 25-2 and CC-WE] Groundwater is generally more energy intensive than surface water. [Box CC-WE]

Linkages among water, energy, food/feed/fiber, and climate are strongly related to land use and management, such as afforestation, which can affect water as well as other ecosystem services, climate, and water cycles (*robust evidence*, *high agreement*). Land degradation often reduces efficiency of water and energy use (e.g., resulting in higher fertilizer demand and surface runoff), and many of these interactions can compromise food security. On the other hand, afforestation activities to sequester carbon have important co-benefits of reducing soil erosion and providing additional (even if only temporary) habitat, but may reduce renewable water resources. [3.7, 4.4, Boxes 25-10 and CC-WE]

Consideration of the interlinkages of energy, food/feed/fiber, water, land use, and climate change has implications for security of supplies of energy, food, and water; adaptation and mitigation pathways; air pollution reduction; and health and economic impacts. This nexus is increasingly recognized as critical to effective climate-resilient-pathway decision making (*medium evidence*, *high agreement*), although tools to support local- and regional-scale assessments and decision support remain very limited.

Working Group II Frequently Asked Questions

These FAQs provide an entry point to the approach and scientific findings of the Working Group II contribution to the Fifth Assessment Report. For summary of the scientific findings, see the Summary for Policymakers (SPM) and Technical Summary (TS). These FAQs, presented in clear and accessible language, do not reflect formal assessment of the degree of certainty in conclusions, and they do not include calibrated uncertainty language presented in the SPM, TS, and underlying chapters. The sources of the relevant assessment in the report are noted by chapter numbers in square brackets.

FAQ 1: Are risks of climate change mostly due to changes in extremes, changes in average climate, or both?

[Chapters 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 18, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30; TS]

People and ecosystems across the world experience climate in many different ways, but weather and climate extremes strongly influence losses and disruptions. Average climate conditions are important. They provide a starting point for understanding what grows where and for informing decisions about tourist destinations, other business opportunities, and crops to plant. But the impacts of a change in average conditions often occur as a result of changes in the frequency, intensity, or duration of extreme weather and climate events. It is the extremes that place excessive and often unexpected demands on systems poorly equipped to deal with those extremes. For example, wet conditions lead to flooding when storm drains and other infrastructure for handling excess water are overwhelmed. Buildings fail when wind speeds exceed design standards. For many kinds of disruption, from crop failure caused by drought to sickness and death from heat waves, the main risks are in the extremes, with changes in average conditions representing a climate with altered timing, intensity, and types of extremes.

FAQ 2: How much can we say about what society will be like in the future, in order to plan for climate change impacts?

[Chapters 1, 2, 14, 15, 16, 17, 20, and 21; TS]

Overall characteristics of societies and economies, such as population size, economic activity, and land use, are highly dynamic. On the scale of just 1 or 2 decades, and sometimes in less time than that, technological revolutions, political movements, or singular events can shape the course of history in unpredictable ways. To understand potential impacts of climate change for societies and ecosystems, scientists use scenarios to explore implications of a range of possible futures. Scenarios are not predictions of what will happen, but they can be useful tools for researching a wide range of "what if" questions about what the world might be like in the future. They can be used to study future emissions of greenhouse gases and climate change. They can also be used to explore the ways climate-change impacts depend on changes in society, such as economic or population growth or progress in controlling diseases. Scenarios of possible decisions and policies can be used to explore the solution space for reducing greenhouse gas emissions and preparing for a changing climate. Scenario analysis creates a foundation for understanding risks of climate change for people, ecosystems, and economies across a range of possible futures. It provides important tools for smart decision making when both uncertainties and consequences are large.

FAQ 3: Why is climate change a particularly difficult challenge for managing risk?

[Chapters 1, 2, 16, 17, 19, 20, 21, and 25; TS]

Risk management is easier for nations, companies, and even individuals when the likelihood and consequences of possible events are readily understood. Risk management becomes much more challenging when the stakes are higher or when uncertainty is greater. As the WGII AR5 demonstrates, we know a great deal about the impacts of climate change that have already occurred, and we understand a great deal about expected impacts in the future. But many uncertainties remain, and will persist. In particular, future greenhouse gas emissions depend on societal choices, policies, and technology advancements not yet made, and climate-change impacts depend on both the amount of climate change that occurs and the effectiveness of development in reducing exposure and vulnerability. The real challenge of dealing effectively with climate change is recognizing the value of wise and timely decisions in a setting where complete knowledge is impossible. This is the essence of risk management.

FAQ 4: What are the timeframes for mitigation and adaptation benefits?

[Chapters 1, 2, 16, 19, 20, and 21; TS]

Adaptation can reduce damage from impacts that cannot be avoided. Mitigation strategies can decrease the amount of climate change that occurs, as summarized in the WGIII AR5. But the consequences of investments in mitigation emerge over time. The constraints of existing infrastructure, limited deployment of many clean technologies, and the legitimate aspirations for economic growth around the world all tend to slow the deviation from established trends in greenhouse gas emissions. Over the next few decades, the climate change we experience will be determined primarily by the combination of past actions and current trends. The near-term is thus an era where short-term risk reduction comes from adapting to the changes already underway. Investments in mitigation during both the near-term and the longer-term do, however, have substantial leverage on the magnitude of climate change in the latter decades of the century, making the second half of the 21st century and beyond an era of climate options. Adaptation will still be important during the era of climate options, but with opportunities and needs that will depend on many aspects of climate change and development policy, both in the near term and in the long term.

FAQ 5: Can science identify thresholds beyond which climate change is dangerous?

[Chapters 1, 2, 4, 5, 6, 16, 17, 18, 19, 20, and 25; TS]

Human activities are changing the climate. Climate-change impacts are already widespread and consequential. But while science can quantify climate change risks in a technical sense, based on the probability, magnitude, and nature of the potential consequences of climate change, determining what is dangerous is ultimately a judgment that depends on values and objectives. For example, individuals will value the present versus the future differently and will bring personal worldviews on the importance of assets like biodiversity, culture, and aesthetics. Values also influence judgments about the relative importance of global economic growth versus assuring the well-being of the most vulnerable among us. Judgments about dangerousness can depend on the extent to which one's livelihood, community, and family are directly exposed and vulnerable to climate change. An individual or community displaced by climate change might legitimately consider that specific impact dangerous, even though that single impact might not cross the global threshold of dangerousness. Scientific assessment of risk can provide an important starting point for such value judgments about the danger of climate change.

FAQ 6: Are we seeing impacts of recent climate change?

[Chapters 3, 4, 5, 6, 7, 11, 13, 18, 22, 23, 24, 25, 26, 27, 28, 29, and 30; SPM]

Yes, there is strong evidence of impacts of recent observed climate change on physical, biological, and human systems. Many regions have experienced warming trends and more frequent high-temperature extremes. Rising temperatures are associated with decreased snowpack, and many ecosystems are experiencing climate-induced shifts in the activity, range, or abundance of the species that inhabit them. Oceans are also displaying changes in physical and chemical properties that, in turn, are affecting coastal and marine ecosystems such as coral reefs, and other oceanic organisms such as mollusks, crustaceans, fishes, and zooplankton. Crop production and fishery stocks are sensitive to changes in temperature. Climate change impacts are leading to shifts in crop yields, decreasing yields overall and sometimes increasing them in temperate and higher latitudes, and catch potential of fisheries is increasing in some regions but decreasing in others. Some indigenous communities are changing seasonal migration and hunting patterns to adapt to changes in temperature.

FAQ 7: Are the future impacts of climate change only negative? Might there be positive impacts as well?

[Chapters 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 19, 22, 23, 24, 25, 26, 27, and 30]

Overall, the report identifies many more negative impacts than positive impacts projected for the future, especially for high magnitudes and rates of climate change. Climate change will, however, have different impacts on people around the world and those effects will vary not only by region but over time, depending on the rate and magnitude of climate change. For example, many countries will face increased challenges for economic development, increased risks from some diseases, or degraded ecosystems, but some countries will probably have increased opportunities for economic development, reduced instances of some diseases, or expanded areas of productive land. Crop yield changes will vary with geography and by latitude. Patterns of potential catch for fisheries are changing globally as well, with both positive and negative consequences. Availability of resources such as usable water will also depend on changing rates of precipitation, with decreased availability in many places but possible increases in runoff and groundwater recharge in some regions like the high latitudes and wet tropics.

FAQ 8: What communities are most vulnerable to the impacts of climate change?

[Chapters 8, 9, 12, 13, 19, 22, 23, 26, 27, 29, and Box CC-GC]

Every society is vulnerable to the impacts of climate change, but the nature of that vulnerability varies across regions and communities, over time, and depends on unique socioeconomic and other conditions. Poorer communities tend to be more vulnerable to loss of health and life, while wealthier communities usually have more economic assets at risk. Regions affected by violence or governance failure can be particularly vulnerable to climate change impacts. Development challenges, such as gender inequality and low levels of education, and other differences among communities in age, race and ethnicity, socioeconomic status, and governance can influence vulnerability to climate change impacts in complex ways.

FAQ 9: Does climate change cause violent conflicts?

[Chapters 12, 19]

Some factors that increase risks from violent conflicts and civil wars are sensitive to climate change. For example, there is growing evidence that factors like low per capita incomes, economic contraction, and inconsistent state institutions are associated with the incidence of civil wars, and also seem to be sensitive to climate change. Climate-change policies, particularly those associated with changing rights to resources, can also increase risks from violent conflict. While statistical studies document a relationship between climate variability and conflict, there remains much disagreement about whether climate change directly causes violent conflicts.

FAQ 10: How are adaptation, mitigation, and sustainable development connected?

[Chapters 1, 2, 8, 9, 10, 11, 13, 17, 20, 22, 23, 24, 25, 26, 27, and 29]

Mitigation has the potential to reduce climate change impacts, and adaptation can reduce the damage of those impacts. Together, both approaches can contribute to the development of societies that are more resilient to the threat of climate change and therefore more sustainable. Studies indicate that interactions between adaptation and mitigation responses have both potential synergies and tradeoffs that vary according to context. Adaptation responses may increase greenhouse gas emissions (e.g., increased fossil-based air conditioning in response to higher temperatures), and mitigation may impede adaptation (e.g., increased use of land for bioenergy crop production negatively impacting ecosystems). There are growing examples of co-benefits of mitigation and development policies, like those which can potentially reduce local emissions of health-damaging and climate-altering air pollutants from energy systems. It is clear that adaptation, mitigation, and sustainable development will be connected in the future.

FAQ 11: Why is it difficult to be sure of the role of climate change in observed effects on people and ecosystems?

[Chapter 3, 4, 5, 6, 7, 11, 12, 13, 18, 22, 23, 24, 25, 26, 27, 28, 29, and 30]

Climate change is one of many factors impacting the Earth's complex human societies and natural ecosystems. In some cases the effect of climate change has a unique pattern in space or time, providing a fingerprint for identification. In others, potential effects of climate change are thoroughly mixed with effects of land use change, economic development, changes in technology, or other processes. Trends in human activities, health, and society often have many simultaneous causes, making it especially challenging to isolate the role of climate change.

Much climate-related damage results from extreme weather events and could be affected by changes in the frequency and intensity of these events due to climate change. The most damaging events are rare, and the level of damage depends on context. It can therefore be challenging to build statistical confidence in observed trends, especially over short time periods. Despite this, many climate change impacts on the physical environment and ecosystems have been identified, and increasing numbers of impacts have been found in human systems as well.