Climate Change 2014: Impacts, Adaptation, and Vulnerability

SUMMARY FOR POLICYMAKERS

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INTRODUCTION

The Working Group II (WGII) contribution to the IPCC's Fifth Assessment Report (AR5) assesses the shifting patterns of risks and opportunities associated with climate change and provides information on how risks can be reduced through mitigation and adaptation.

Box SPM.1 defines central concepts, and Box SPM.2 introduces terms used to convey the degree of certainty in findings. Chapter sections in square brackets indicate the assessment supporting findings in this summary.

_____ START BOX SPM.1 HERE _____

Box SPM.1. Terms Critical for Understanding the Summary

Climate change: 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 modulation of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. In contrast, 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 that alter the atmospheric composition, and climate variability attributable to natural causes.

Exposure: The presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected.

Vulnerability: The propensity or predisposition to be adversely affected.

Impacts: Effects on natural and human systems. In this report, the term "impacts" is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change.

Risk: The potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain. Risk is often represented as probability of occurrence of a hazardous event(s) multiplied by the consequences if the event(s) occurs. This report assesses climate-related risks.

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

Transformation: A change in the fundamental attributes of a system, often based on altered paradigms, goals, or values. Transformations can occur in technological or biological systems, financial structures, and regulatory, legislative, or administrative regimes.

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Box SPM.2. Communication of the Degree of Certainty in Assessment Findings

The WGII AR5 relies on two metrics for communicating the degree of certainty in assessment findings:

- Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, 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 expert judgment.

Each finding has its foundation in an author team's evaluation of associated evidence and agreement. The summary terms to describe available evidence are: *limited*, *medium*, or *robust*; and the degree of agreement: *low*, *medium*, or *high*. Levels of confidence include five qualifiers: *very low*, *low*, *medium*, *high*, and *very high*. When author teams evaluate the likelihood of some well-defined outcome having occurred or occurring in the future, a finding can include likelihood terms: v*irtually certain,* 99–100% probability; *very likely,* 90–100%; *likely,* 66–100%; *about as likely as not,* 33–66%; *unlikely,* 0–33%; *very unlikely,* 0–10%; and *exceptionally unlikely,* 0–1%. Additional terms used: *extremely likely,* 95– 100% probability; *more likely than not,* >50–100%; and *extremely unlikely,* 0–5%.

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A) IMPACTS, VULNERABILITIES, AND ADAPTATION IN A COMPLEX AND CHANGING WORLD

A.i. Observed Impacts and Vulnerabilities

Impacts of recent observed climate change on physical, biological, and human systems have been detected on all continents and in most oceans (*high confidence*). This conclusion is strengthened by observations since the IPCC Fourth Assessment Report (AR4) and through more extensive analyses of earlier observations. Most reported impacts of climate change are attributed to regional atmospheric and oceanic warming, with lower confidence in attribution to shifts in rainfall patterns. For many natural systems on land and in the ocean, new or stronger evidence exists for substantial and wide-ranging climate change impacts. For managed ecosystems and human systems, effects of changing social and economic factors often dominate over direct impacts of climate change. See Table SPM.1 for regional examples. [18.3-18.6]

[INSERT TABLE SPM.1 HERE

Table SPM.1: Observed impacts attributed to climate change with *medium* (*) or *high* (**) confidence, for physical, biological, and human systems across eight major world regions. [Tables 18-6, 18-7, 18-8, 18-9]]

Climatic and biophysical drivers interact with non-climatic drivers of vulnerability and exposure to shape differential risks and impacts (*very high confidence*). See Box SPM.3. Vulnerability and exposure of communities or social-ecological systems to climatic hazards are dynamic and thus varying across temporal and spatial scales. [13.1, 14.1, 14.2, 15.2.4, 19.6.1]

Impacts from recent extreme climatic events show significant vulnerability of some ecosystems and many human systems to current climate variability (*very high confidence*). These experiences are consistent with a significant adaptation deficit in developing and developed countries for some sectors and within some regions. [10.3.1, 10.7.3, 13.2.1, 18.4.4, 18.4.7, 25.8.1, 26.6, 26.7, Tables 18-4, 23-3, 25-1, Boxes 25-5, 25-6, 25-8]

Hydrological systems have changed in many regions due to changing rainfall or melting glaciers, affecting water resources, water quality, and sediment transport (*medium confidence*). The duration of droughts in some regions has been altered by climate change. In many river systems, the frequency of floods has been altered by climate change (*low* to *medium confidence*). Widespread changes and degradation of permafrost in high-latitude and high-elevation mountain regions have been observed over the past years and decades (*high confidence*). [3.2.3, 18.3.1, 18.5]

Terrestrial plant and animal species have shifted their ranges and seasonal activities and altered their abundance, in response to climate change in the past, and they are doing so now in many regions (*high confidence*). Increases in the frequency or intensity of ecosystem disturbances due to fires, pest outbreaks, wind-storms, and droughts have been detected in many parts of the world (*medium confidence*). There is *very low confidence* that most observed species extinctions can be attributed to recent climate warming. However, recent warming has played a role in extinctions of Central American amphibians (*medium confidence*). [4.2-4.4, 18.3.2, 18.5]

Several major terrestrial ecosystems are undergoing broad-scale changes that can be characterized as early warnings for coming regime shifts, in part due to climate change. Climate change is a driver of widespread shrub encroachment in the Arctic tundra (*high confidence*) and of boreal forest tree mortality (*low confidence*). In Central and South America, conversion of natural ecosystems is currently the main cause of biodiversity and ecosystem loss and a driver of anthropogenic climate change. However, observed recession and degradation of the Amazon forest cannot be attributed to climate change. [18.3.2, 18.5.6, 18.5.7, 27.2.2, 27.3.2]

Warming is causing shifts in marine species' geographical distribution, abundance, migration patterns, and timing of seasonal activities, resulting in altered species interactions (*high confidence*). There are many observations of poleward shifts in the distribution and abundance of fishes and invertebrates and/or of their shifts to deeper and cooler waters. Warming-induced stratification, reduced intensity of ocean circulation, and the breakdown of organic matter by organisms are expanding hypoxic regions that constrain the habitat of oxygen-dependent marine animals, plants, and microbes. In Earth history, natural climate change at rates slower than today's anthropogenic change has led to significant ecosystem shifts in the oceans. [6.1-3, 6.5, 18.3, 30.4-5, Box CC-CR]

Effects of climate change on food production are evident in several regions (*high agreement, medium evidence*). Yields have increased in mid-to-high-latitude regions due to warming and higher CO_2 (*low confidence*) and decreased in other, mainly low-latitude regions due to water shortages and higher temperatures (*medium confidence*). Overall, negative impacts have been more common than positive ones (*high confidence*). Since AR4, there have been several periods of rapid food price increases, demonstrating partial sensitivity of current markets to climate variability. Interactions among production factors (e.g., CO_2 and ozone, mean temperature, extremes, water, nitrogen) can alter primary food production in complex ways (*high agreement, medium evidence*). [7.2, 7.3, 7.4, 18.4.1, Figures 7-2 to 7-7, Tables 7-1, 18-9]

Prevailing rural development constraints, such as low levels of educational attainment, environmental degradation, gender inequality, and remoteness from decisionmakers, create additional vulnerabilities to climate change (*high confidence*). In developing countries, rural people are subject to multiple non-climate stressors, such as under-investment in agriculture and land-policy problems (*high* to *very high confidence*). [9.2, 9.3.1, 9.3.5, 9.4.4, Table 9-1]

In recent decades, climate change has *likely* contributed to levels of ill-health though the present world-wide burden of ill-health from climate change is relatively small compared with other stressors on health and is not well quantified. Changes in temperature, rainfall, and sea-level have altered distribution of some disease vectors, increased heat wave casualties, and reduced food production for vulnerable populations (*medium confidence*). Climate change is a multiplier of existing vulnerabilities affecting health outcomes (*high confidence*). [11.3, 11.4, 18.4.5, 22.3.5, Box 11-4]

People living in places affected by violent conflict are particularly vulnerable to climate change (*high agreement, limited evidence*). A causal effect of climate change and variability on violence is contested, although there is *robust evidence* that shows that low per capita incomes, economic contraction, and inconsistent state institutions, factors sensitive to climate change, are associated with the incidence of civil wars. [12.5, 19.6.1]

Climate change constitutes an additional burden for the rural and urban poor (*very high confidence*). Urban and rural transient poor who face multiple deprivations can slide into chronic poverty as a result of extreme weather events, or a series of events, when they are unable to rebuild their eroded assets (*high agreement, limited evidence*). Preexisting gender inequalities are increased or highlighted by weather events and climate. Often, the more affluent can better take advantage of shocks and crises, given their flexible assets and power status. [13.1, 13.2.1, 13.3]

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Box SPM.3. Multidimensional Vulnerability to Climate Change

People who are socially, economically, culturally, politically, or institutionally marginalized are typically most at risk from adverse impacts of climate change and climate change responses. Such heightened vulnerability is related not only to income and assets but also to gender, class, race, ethnicity, age, and (dis)ability (Box SPM.3 Figure 1). Other dimensions include resource access, location, legal systems, and voice. Understanding differential adaptive capacity for individuals, households, and communities requires attention to multidimensional inequality, deprivation, and power. It also benefits from attention to context-specific interactions in social-ecological systems that contribute to differential vulnerability. [8.1.4, 9.3.5, 9.4.1, 11.4.1, 11.5, 13.2.1, 19.6.1]

[INSERT BOX SPM.3 FIGURE 1 HERE
Box SPM.3 Figure 1: Intersecting, simultaneous, and dynamic axes of privilege and marginalization, shaped by people's multiple identities and embedded in uneven power relations and development pathways. Together, they result in differential vulnerability to the same exposure to climate change and climate responses. [Figure 13-4]]

_____ END BOX SPM.3 HERE _____

A.ii. Adaptation Experience

Human and natural systems respond to climate and its effects. Natural systems have some potential to adapt, and are adapting, through ecological and evolutionary processes, and humans may intervene to promote particular adjustments. Responses in human systems include coping with climate variability and extremes, and managing risks through planned adaptation to climate change impacts. Adaptation can be motivated by broader vulnerability-reduction and development objectives, such as reducing existing adaptation deficits to current climate. [14.1]

Adaptation activity is increasing and becoming more integrated within wider policy frameworks (*high confidence*). Adaptation planning is transitioning from a phase of awareness and promotion to the construction of responses in societies (*high agreement*, *robust evidence*). [14.3.4, 14.4.2, 15.2, 15.3.1]

Awareness of climate risks and vulnerabilities, and the need for adaptation, does not always lead to action (*high confidence*). Numerous assessments have led to higher awareness among decisionmakers and stakeholders of climate risks and adaptation needs and options. However, in most cases this awareness of changing risks has not been translated into adjustments of ongoing activities or risk management planning. In order to facilitate such integration into decision-making, assessments may need to be linked more directly to particular decisions, with information tailored to support the decisionmaking process. [2.3, 14.5, 14.6]

The diversity of adaptation experience, including corresponding constraints and opportunities, can be seen in specific geographic contexts (see also Table SPM.2):

- **The scale and concentration of urban climate risk and hence the need for adaptation are being acknowledged, but responses are weak except for a handful of cities largely in high-income countries (*medium confidence*).** Examples of approaches to adaptation have included the designation of a unit within city government with responsibility for adaptation, measures to involve key sectors so they understand why they need to engage with adaptation, local champions to initiate measures and ensure continuity, and the importance of dialogue and discussion with all key stakeholders. City-based disaster risk reduction is a strong foundation around which to build urban climate resilience (*high confidence*). [8.2, 8.3, 8.4, 8.5]
- **Gender, the supply of information for decision-making, and the role of social capital in building resilience are all key issues for adaptation in rural areas (*high confidence*).** Constraints to adaptation come from lack of access to credit, land, water, technology, markets, and information, and constraints are particularly pronounced in developing countries. [9.4.1, 9.4.3, 9.4.4]
- **In many African countries, national governments are initiating governance systems for adaptation (*high agreement, medium evidence*).** Efforts such as disaster risk reduction, social protection, climate-resilient infrastructure, ecosystem restoration, and livelihood diversification are reducing vulnerability and enhancing resilience, but this is still largely confined to local scales and isolated initiatives. [22.4.4, 22.4.5, 22.6.2]
- **In Europe, adaptation policy has been developed at international (EU), national, and local government levels, but so far evidence relates to studies of the prioritization of options, and there is limited systematic information on current implementation or effectiveness.** Some adaptation planning has been integrated into coastal and water management, as well as disaster risk management. There is little evidence of adaptation planning in rural development, land-use planning, or conservation. [23.6.4, 23.7, Box 23-2]
- **In Australasia, adaptation is already occurring and adaptation planning is becoming embedded in planning processes, mostly at the conceptual rather than implementation level (*high agreement, robust evidence*).** Planning for sea-level rise and, in Australia, for reduced water availability is becoming widely adopted. Adaptive capacity is generally high in many Australasian human systems, but implementation faces major constraints especially for transformative responses at local and community levels (*high confidence*). Constraints on implementation arise from: uncertainty of projected impacts; limited financial and human resources; limited integration of different levels of governance; and different values and beliefs relating to the existence of climate change and to objects and places at risk. [25.4, 25.10.3, Boxes 25-1, 25-2, and 25-9]

- **In North America, while different tiers of government are assessing their climate vulnerabilities and designing adaptation actions and programs, there has been more leadership in adaptation planning at the local level (*high confidence*).** Important barriers exist to effective adaptation such as path dependency, asymmetries in access to information, top-down decision making, and lack of assets, options, funding, staff, horizontal and vertical coordination, and social capital. The few examples of proactive adaptation anticipating future climate impacts are largely found in sectors with longer-term decision-making, including energy and public infrastructure. [26.7, 26.8, 26.9]
- **In the Arctic, indigenous people have a high adaptive capacity and have begun to develop novel solutions to adapt to climate changes combining traditional and scientific knowledge and co-producing climate studies with scientific partners.** [28.2.4, 28.2.7, 28.4.1]

[INSERT TABLE SPM.2 HERE
Table SPM.2: Illustrative examples of adaptation experience, as well as approaches to reduce vulnerability and enhance 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 vulnerabilities, inequalities, and climate change come to the fore. At the same time, place-based examples illustrate how larger-level drivers and stressors shape differential risks and livelihood trajectories, often mediated by institutions.]

B) DECISIONMAKING IN A COMPLEX WORLD: UNDERSTANDING APPROACHES TO MANAGING RISKS THROUGH ADAPTATION

Managing the risks of climate change involves decisions with implications for future society, economies, environment, and climate. Robust decisions can be effective across a range of possible futures (see Box SPM.4). Fundamentally, adaptation to climate change can be considered an iterative process with continuing learning about risks and the effectiveness of risk management actions.

B.i. Determinants and Iterative Management of Risk

Risk in the context of climate change is produced through the interaction of changing physical characteristics of the climate system with evolving characteristics of human, socioeconomic, and biological systems (exposure and vulnerability). See Figure SPM.1. Alternative development paths influence risk both by changing the likelihood of physical impacts (through their effects on greenhouse gas emissions) and by altering vulnerability and exposure. [2.1.1, 19.1, 19.2, Fig.19-1]

Due to the uncertainty, dynamic complexity, and short-to-long timeframes associated with climate change, robust adaptation efforts require iterative risk management strategies (*high agreement, medium evidence*). While no-regret, low-regret, and win-win strategies have attracted attention in the past, there is increasing recognition that adaptive responses will entail acting in the face of continuing uncertainty about the extent of climate change, the nature of its impacts, and adaptation needs. Iterative risk management involves an ongoing process of assessment, action, reassessment, and response that may need to be applied under climate change for decades, if not longer. Monitoring and evaluation are important learning tools in this process. See Figure SPM.2. [2.1.2, 2.2.1, 2.3.1, 14.1, 14.3.4, 15.2.3, 15.3.3, 20.5]

[INSERT FIGURE SPM.1 HERE
Figure SPM.1: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. Vulnerability and exposure are, as the figure shows, largely the result of socioeconomic development pathways and societal conditions. Changes in both the climate system (left) and development processes (right) are key drivers of the different core components (vulnerability, exposure, and physical hazards) that constitute risk. The definition and use of “key” and “emergent” are indicated in Section C.ii. [19.1, Figure 19-1]]

[INSERT FIGURE SPM.2 HERE
Figure SPM.2: Illustration of iterative response to climate change. (A) Four main phases of planned adaptation as a cyclic, iterative process: needs, planning, implementation, and evaluation. Efforts in adaptation can be linked with development or disaster risk management. Adaptation governance at multiple scales underlies capacity. (B) In the

context of iterative risk management, each individual adaptation decision cycle comprises well known aspects of risk assessment and management. (C) A sequence of adaptation decisions creates an adaptation pathway. Some decisions, and sequences of decisions, are more likely to result in long-term maladaptive outcomes than others, but there is no single correct adaptation pathway and judgment of outcomes depends strongly on societal values, expectations, and goals. [Figures 15-1, 16-2, 25-6]]

B.ii. Principles for Effective Adaptation

Experience in the practice of adaptation serves to clarify the opportunities for, and the most significant barriers to, adaptation and the synergies and tradeoffs with other societal goals. Types of responses to climate change are overviewed in Table SPM.3.

[INSERT TABLE SPM.3 HERE
Table SPM.3: Entry points, strategies, measures, and options for managing the risks of climate change. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples given can be relevant to more than one category.]

Actors at all geographical and institutional levels and in different development contexts have opportunities to facilitate, initiate, and implement effective adaptation action (*medium agreement, medium evidence*). Because adaptation is a multidimensional issue involving many state and non-state actors functioning at local to global scales, coordination of roles and responsibilities enhances institutional networking for effective implementation (*high agreement*, *medium evidence*) (Figure SPM.2A). National governments assume a coordinating role of adaptation actions in subnational and local levels of government, including the provision of information and policy frameworks, creation of legal frameworks, actions to protect vulnerable groups, and financial support to other levels of government (*high agreement*, *robust evidence*). Among the many actors and roles associated with adaptation, those associated with local governance and with the private sector are increasingly recognized as critical to progress (*high confidence*), as these groups bear responsibility for translating the top-down flow of risk information and financing, and for scaling up efforts of communities and households in identifying and implementing selected adaptation actions. [2.3.4, 14.4, 15.2.2, 15.2.3, 15.4, 16.6]

Strategies and actions can be pursued now that increase climate resilience while at the same time helping to improve human livelihoods, social and economic well-being, and responsible environmental management (*high confidence*). Adaptation actions can provide significant co-benefits such as alleviating poverty and enhancing development especially in developing countries. Improving resilience through an emphasis on disaster risk reduction has become increasingly common (*high agreement, medium evidence*). Efforts to improve ecosystem resilience can benefit adaptation. Building climate resilience in cities can involve ecosystem-based adaptation with water and food systems as foci (*medium confidence*). [2.3.4, 2.4.2, 8.3, 8.5, 14.3.4, 14.4.2, 15.2, 15.3.1, 17.2.7, 17.4.4, 20.6.2, 29.6]

Mainstreaming facilitates integration of adaptation into planning and decisionmaking and embeds climate-sensitive thinking in existing and new institutions and organizations (*high confidence*). Mainstreaming promotes synergies with development planning, enables the blending of multiple funding streams, and reduces the possibility of maladaptive actions. [14.3.4, 14.4.2, 16.6, 17.2.7, 17.4.4]

Constraints to adaptation planning and implementation include availability of resources and uncertainties about future climate and disaster risk at national and regional scales (*high agreement, robust evidence*). The manner in which constraints manifest and their implications for capacity to achieve adaptation objectives vary significantly across regions and sectors and across social and temporal scales. [16.2, 16.3, 17.2.6, 17.3, 17.5.4]

Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts (*high confidence*). Instruments comprise risk sharing and transfer mechanisms, loans including public-private finance partnerships, payment for environmental services, improved resource pricing (water markets), charges and subsidies including land taxes, direct investment, norms and regulations, behavioral approaches, and institutional innovations. Applicable risk financing mechanisms across scales comprise informal and traditional risk sharing, such as relying on kinship networks, as well as market-based instruments including microinsurance, insurance, reinsurance, and national, regional, and global risk pools (*medium confidence*). [8.4, 10.7, 10.9, 17.3.4, 17.3.6, 17.4, 17.5]

Intervention in one location or sector can increase the vulnerability of another location or sector, or increase the vulnerability of the target group to future climate change (*medium confidence*). Such maladaptation can result from decisions where greater emphasis is placed on short-term outcomes ahead of longer-term threats, or from decisions that discount, or fail to consider, the full range of interactions arising from planned actions. See also Figure SPM.2C. [14.7.1, 14.7.2]

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Box SPM.4. Characterizing the Future

While there are many possible scenarios for future climate change and societal development, current decisions narrow future options. New risks will emerge in the coming decades as a result of past emissions and current socioeconomic trends. Societal responses, particularly adaptations, will influence outcomes during this era of climate responsibility. In contrast, benefits of current mitigation efforts will emerge over a longer period. Future risks during this longer-term era of climate options are thus linked to current mitigation and development choices.

Trends in vulnerability, exposure, and climate, as well as weather and seasonal forecasting of climate variability, can inform decisions in the era of climate responsibility. Climate and impact model projections become increasingly relevant for climate-affected decisions playing out over the longer term, recognizing that uncertainties about future vulnerability and exposure also increase over time. [21.3.3, 21.5.1, 21.5.3]

Scenarios are a vital part of managing uncertainty. [2.2.1] Scenarios provide a mechanism for characterizing possible socioeconomic futures and climate change outcomes. Socioeconomic factors influence not only greenhouse gas emissions but also the size and location of populations at risk from various climate change impacts, the differential vulnerability of these populations, and their capacities to adapt.

Modeled future impacts assessed in this report draw on a combination of climate model simulations using SRES scenarios (CMIP3) and new climate model simulations using the Representative Concentration Pathway (RCP) scenarios (CMIP5). The four RCPs reflect different levels of mitigation, leading to 21st century radiative forcing levels of 2.6, 4.5, 6.0, and 8.5 W m^{-2} (see WGI AR5 Chapters 1, 6, 11, and 12). Box SPM.4 Figure 1 illustrates alternative climate futures, under RCPs 4.5 and 8.5, along with observed temperature and precipitation changes. [1.1.3, Box CC-RC]

[INSERT BOX SPM.4 FIGURE 1 HERE
Box SUM.4 Figure 1: Changes in annual average temperature (A) and precipitation (B). For observations (top map, A and B; CRU), differences are shown over land between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For projections (bottom four maps, A and B; CMIP5), four classes of results are displayed. (1) White indicates areas where for >66% of models the annual average change is less than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Thus in these regions, more than 2/3 of models show no significant change in the annual average using this measure of significance, although this does not imply no significant change at seasonal or shorter time-scales such as months to days. (2) Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. In these regions, more than 2/3 of models show a significant change in annual average, but less than 2/3 agree on whether it will increase or decrease. (3) Colors with white circles indicate the change averaged over all models where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on whether the annual average will increase or decrease. In these regions, more than 2/3 of models show a significant change in annual average and more than 2/3 (but less than 90%) agree on whether it will increase or decrease. (4) Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on whether the annual average will increase or decrease. For models that have provided multiple realizations for the climate of the recent past and the future, results from each realization were first averaged to create the baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-

noise ratios were calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065. See also Annex I of WGI AR5. [Box CC-RC]]

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C) FUTURE RISKS AND CHOICES: RISKS AND POTENTIAL FOR ADAPTATION

Assessment of the full range of potential future impacts, not only the most likely outcomes, provides a basis for understanding future risks. This section covers future risks across sectors and regions, and their sensitivity to the magnitude and rate of climate change, to characteristics of development that affect vulnerability, and to policy choices. It elucidates how and when choices matter in reducing future risks and highlights the differing timeframes for mitigation and adaptation benefits within the eras of climate responsibility and climate options.

C.i. Sectoral and Regional Risks

Freshwater resources

Projected climate changes would change hydrological regimes substantially (*high agreement, robust evidence*). Runoff and groundwater recharge are projected to increase at high latitudes and in the wet tropics, and to decrease in most dry tropical regions, controlled mainly by changes in precipitation. Projected climate changes imply large changes in the frequency of floods. Climate change is projected to reduce renewable water resources in most semi-arid and arid regions, potentially affecting food security. Impacts of climate change on water resources are expected to reduce economic growth, particularly in developing countries (*high agreement, limited evidence*). [3.2.5, 3.4, 3.5, 3.6.5, Table 3-2, WGI AR5 12.4.5]

Adaptive water management techniques, such as scenario planning, learning-based approaches, and flexible solutions, offer an opportunity to address uncertainty due to climate change (*high agreement, limited evidence*). Barriers include lack of technical capacity, financial resources, awareness, and communication. A low-emissions pathway reduces damage costs and costs of adaptation. [3.4, 3.5, 3.6, 3.7.2]

Terrestrial and inland water systems

Direct human impacts such as land-use change, pollution, and water resource development will continue to dominate threats to freshwater ecosystems (*high confidence*) and terrestrial ecosystems (*medium confidence*) with climate change becoming an increasing additional stress through the century, especially for high-warming scenarios (e.g., RCP 6.0 and 8.5). Even for mid-range rates of climate change (i.e., RCP 4.5 and 6.0 scenarios) many species will be unable to move fast enough to track suitable climates (*medium confidence*). See Figure SPM.3. Projected climate changes imply increased extinction risk for a substantial fraction of species during and beyond the 21st century, especially as climate change interacts with other pressures, such as habitat modification, over-exploitation, and invasive species (*very high confidence*). Forests may be more sensitive to future climate change than reported in AR4, and tree mortality and forest dieback could become a problem in many regions much sooner than previously anticipated (*medium confidence*). [4.2.4, 4.3, 4.4.1, Box CC-RF]

Carbon stored in land and freshwater ecosystems in the form of plant biomass and soil organic matter has increased over the past two decades (*virtually certain*). The terrestrial carbon sink is offset to a large degree by carbon released to the atmosphere through forest conversion to farm and grazing land and through forest degradation (*high confidence*). The carbon stored thus far in terrestrial ecosystems is vulnerable to loss back to the atmosphere as a result of climate change and land-use change (*medium confidence*). [4.2, 4.3, Box 4-4]

Management actions can reduce, but not eliminate, exposure to climate-driven ecosystem impacts and can increase ecosystem adaptability (*high confidence*). Adaptive capacity of ecosystems can be increased by reducing other stresses, maintaining a large pool of genetic diversity and functional evolutionary processes, assisting translocation, and manipulating disturbance regimes. [4.4.1, 4.4.3]

Terrestrial and freshwater ecosystems can, when pushed by climate change, cross "tipping points" and abruptly change in composition, structure, and function (*high confidence*). The crossing of these tipping

points will result in significant increases in carbon emissions to the atmosphere (*medium confidence*). Examples include abrupt transformation of the ecology and albedo of the boreal-arctic system (*low confidence*) and of the Amazon forest to more open, dry-adapted ecosystems (*low confidence*). [4.2, 4.3.3, Box 4-3, 4-4, Figure 4-10]

[INSERT FIGURE SPM.3 HERE
Figure SPM.3: Synthetic overview of projected abilities of some terrestrial and freshwater species to track climate by movement across landscapes. (A) Rates of climate change for global land areas. Black dotted line shows observed rates of climate change. Other rates were calculated from the CMIP5 ensemble for the historical period (black heavy line, with upper and lower bounds as light black lines) and for the future based on the four RCPs. A lower bound is given for RCP 2.6, and an upper bound for RCP 8.5. (B) Corresponding climate velocities, providing indication of the speed at which species' ranges would need to move to track changing climatic conditions. In mountainous areas with low climate velocities, species would only need to move short distances upslope to track a warming climate. In flat areas with high climate velocities, such as the Amazon basin, species would need to move large distances to track a warming climate. (C) Maximum estimated rates of displacement of several terrestrial and freshwater species groups, indicating how fast these groups can move across landscapes. Rates of species displacement are well defined for plants, especially trees, but less well defined for other groups. Displacement rates do not generally account for biotic interactions or human intervention that may speed or hinder dispersal. The thin red arrows give an example of interpretation: a rate of climate change of 0.065 °C/yr (approximately equal to projected rates by mid-century for RCP 8.5) corresponds to ~2.2 km/yr global average climate velocity. This global-average velocity would exceed projected maximum capacity for displacement for most plants, most primates, many rodents, and some less mobile species of other groups. For RCP 2.6, most species would be able to track climate by mid-century. Color gradient in panel A provides overall representation of the ability of species to track climate change. Detailed spatial analyses and maps of species displacement can be found in the references cited in WGII Chapter 4. E.t ungulates = even-toed ungulates; Phyto. insects = phytophagous (herbivorous) insects; Fw. mollusks = freshwater mollusks. [Figure 4-6]]

Coastal systems and low-lying areas

Due to relative sea-level rise, coastal systems and low-lying areas will increasingly experience adverse impacts associated with submergence and flooding from extreme coastal high water levels (*high confidence*). The population and assets exposed to coastal risk as well as human pressures on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, urbanization, and coastward migration. Under medium population projections, population exposed to the 100-year coastal flood is expected to increase from 271 million in 2010 to 345 million in 2050 due to socioeconomic development only. By 2100, without adaptation, the majority of people projected to be affected by coastal flooding and displaced due to inundation and erosion will be in East, Southeast, and South Asia. In 2100, for medium socioeconomic development assumptions and a 1.26 m sea-level rise, the expected direct global annual cost of coastal flooding may reach 300 US$ billion per year without adaptation and 90 US$ billion per year with adaptation, including costs of adaptation and residual damages. [5.3, 5.4.3, 5.5.3]

Acidification and warming of coastal waters will continue with significant consequences for coastal ecosystems (***high confidence***). The interaction of acidification and warming exacerbates coral bleaching and mortality (*very high confidence*). [5.4.2, 6.2, 6.3, 6.5.2, 30.4, 30.5, Box CC-CR, CC-OA]

Marine systems

Through species gains and losses in response to warming, the diversity of marine animals and plants will increase at mid and high latitudes (*high confidence*) and fall at tropical latitudes (*low confidence*), leading to large-scale redistribution of global catch potential for fishes and invertebrates (*medium confidence*). Animal displacements are projected to lead to a 30–70% increase in the fisheries yield in high-latitude regions but a drop of 40–60% in the tropics by 2055 relative to 2005 under the SRES A1B scenario (*medium confidence* for general trend of shifting fisheries yields, *low confidence* for magnitude of change). See Figure SPM.4. [6.2.5, 6.3, 6.4, 6.5]

Impacts on ocean ecosystems and processes reveal significant regional differences that will benefit from differing policies and adaptation approaches (*medium agreement, medium evidence*). Building dynamic fisheries management and sustainable aquaculture provides opportunities for adaptation to changes in the distribution and productivity of fish stocks (*high agreement, medium evidence*). [6.5, 7.5.1, 30.5.5, 30.6.3]

Changes to surface winds, sea level, wave height, and storm intensity will increase the risks associated with coastal and ocean based industries such as shipping, oil, gas, and mineral extraction (*medium agreement, medium evidence*). New opportunities as well as international issues over access and vulnerability are expected as waters warm, particularly in high latitude regions. [30.6, 6.5]

[INSERT FIGURE SPM.4 HERE
Figure SPM.4: (A) Multi-model mean changes of projected net primary production. To indicate consistency in the sign of change, regions are stippled where all models (four in total) agree on the sign of change. Changes are annual means under SRES A2 for the period 2080 to 2099 relative to 1870 to 1889. (B) A projection of maximum fisheries catch potential of 1000 species of exploited fishes and invertebrates from 2000 to 2050 under SRES A1B. (C) Example of changes occurring within fisheries across the ocean. [Figures 6-14, 6-15, and 30-15]]

Food production systems and food security

Without adaptation, warming of up to 2°C local temperatures is expected to reduce yields on average for the major cereals (wheat, rice, and maize) in temperate regions, although many individual locations may benefit (*medium confidence*). There is confirmation that warming up to 2°C will decrease yields in low-latitude tropical regions (*medium agreement, robust evidence*). Reductions of more than 5% are *more likely than not* beyond 2050 and *likely* by the end of the century. From the 2070s onwards, all of the positive yield changes are in temperate regions, suggesting that yield reduction in the tropics are *very likely* by this time and substantial, particularly for wheat (*high agreement, robust evidence*). [7.4, Figures 7-5, 7-6, and 7-7]

Adaptation possibilities of food systems to climate change show a very wide range in effectiveness. Net benefits of adaptation will increase with increasing local mean temperature up to ~3°C local warming above preindustrial (*medium confidence*). Generally, adaptation leads to lower reductions in food production than in its absence with an overall crop yield difference in adaptation cases of about 15-20% over non-adaptation cases (*high agreement, medium evidence*), with more effective adaptation at higher latitudes (*medium agreement, limited evidence*), but with some adaptation options more effective than others. Benefits of adaptation are greater for wheat, rice, and maize in temperate rather than tropical regions [7.1, 7.3.2, 7.5, 7.6, Figures 7-5, 7-9]

Urban areas

Increasing concentration of populations, assets, and economic activities in the urban areas of almost all countries, irrespective of income level, will increase the concentration of climate-related risks for a large and growing proportion of the world's population (*medium confidence*, based on *high agreement, medium evidence*). Climate change will shift the comparative advantages of cities and regions and differentially threaten or enhance the resource, asset, and economic base and so lead to significant structural changes and impacts on local, national, and potentially the global economy. [8.1, 8.3, 8.4]

Rural areas

Future impacts on rural areas will be mediated in complex ways by changing patterns of extreme events and/or effects of climate change on agriculture and less-managed ecosystems (*high confidence*). Major impacts will be felt through impacts on water supply, food security, and agricultural incomes, including impacts on major non-food cash crops such as coffee. Adaptation can build on current responses to climate variability, in production of food crops, cash crops, and livestock and in water management, but these may not be sufficient to deal with the range of projected climate change. [9.3.3, 9.4.1, 9.4.3]

Climate change will lead to higher prices and increased volatility in agricultural markets, which may undermine global food supply security while differentially affecting net buyers and net sellers of food (*medium* to *high confidence*). Deepening agricultural markets through reforming trade and making institutional efforts to improve the predictability and reliability of the world trading system, as well as by investing in additional supply capacity of small-scale farms in developing countries, could help reduce market volatility and manage food supply shortages that might be caused by climate change (*medium agreement*). [9.3.3]

Monetized impacts of climate change will be significant especially for the developing regions, due to their economic dependence on agriculture and natural resources, low adaptive capacities, and geographical locations (*high confidence*). Valuation of non-marketed ecosystem services and limitations of economic valuation models that aggregate across contexts pose challenges for valuing rural impacts. [9.3.4]

Key economic sectors and services

Climate change would reduce energy demand for heating and increase energy demand for cooling in the residential and commercial sectors (*high agreement, robust evidence*). Energy demand will be influenced by changes in demographics, lifestyles, design and insulation of housing, and energy efficiency. [10.2]

Climate change would affect energy sources and technologies differently, depending on resources (water flow, wind, insolation), technological processes, or locations involved (*high agreement, robust evidence*). Changes in the availability and temperature of water for cooling are the main concern for thermal and nuclear power plants, but several options are available to cope with reduced water availability. Climate change would influence the integrity and reliability of pipelines and electricity grids (*medium agreement, medium evidence*). [10.2]

Human health

In the next few decades, climate change impacts on ill-health include the following (*high confidence*): greater incidence of injury, disease, and death due to more intense heat waves, storms, floods, and fires; increased risk of under-nutrition resulting from diminished food production in poor regions; loss of work capacity and reduced labor productivity in vulnerable populations; increased risks of food- and water-borne diseases and vector-borne infections; and modest improvements in some areas due to lower impacts of cold, shifts in food production, and reduction of disease-carrying vectors. The most effective adaptation measures for health in the immediate term are programs that extend basic public health measures and essential health services, increase capacity for disaster preparedness and response, and alleviate poverty (*very high confidence*). [11.4, 11.5, 11.6, 11.7]

For global mean temperature increase of 4°C above 1986-2005, important limits to adaptation for health impacts may have been exceeded in many areas of the world (*high confidence*). These relate to sea-level rise, storms, loss of agricultural productivity, and daily temperature/humidity conditions that exceed coping mechanisms. See Box SPM.5. [11.8]

Human security

Climate change threatens human security, because it a) undermines livelihoods, b) compromises culture and identity, c) increases migration that people would rather have avoided, and d) undermines the ability of states to provide the conditions necessary for human security (*high agreement, robust evidence*). For populations that are already socially marginalized, are resource dependent, and have limited capital assets, human security may be progressively undermined as the climate changes. [12.1.2, 12.2, 12.3, 12.7]

Climate change will have significant impacts on forms of migration that compromise human security (*medium agreement, medium evidence*). Mobility is a widely used and often effective strategy to maintain livelihoods in response to social and environmental changes (*high agreement, medium evidence*). Legitimate and inclusive planning processes can help alleviate the conflict and insecurity that individuals and communities may experience from implementation of planned resettlement. [9.3.3, 12.3.2, 12.4.2, 12.4.3]

Climate change will lead to new challenges to states and will shape both conditions of security and national security policies (*medium agreement, medium evidence*). Some states are experiencing major challenges to their territorial integrity, including Arctic countries, small island states, and other states highly vulnerable to sea-level rise. Some impacts of climate change, such as changes in sea ice, transboundary and shared water resources, and migration of pelagic fish stocks, have the potential to increase rivalry among states. The presence of robust institutions can manage many of these rivalries such that human security is not severely eroded. [12.5.4, 12.6]

Livelihoods and poverty

Future impacts of weather events and climate will slow down economic growth and poverty reduction, further erode food security, and trigger new poverty traps, the latter particularly in urban areas (*medium confidence,* based on *medium agreement, medium evidence*). Climate change will exacerbate multidimensional poverty in low and lower middle-income countries, including high mountain states and countries with indigenous people affected by sea-level rise and relocation, and create new poverty pockets in upper middle- to high-income countries. Urban and wage-labor dependent poor households, as well as regions with high food insecurity (above all in Africa) and high inequality, will be particularly affected due to food price increases. [10.9, 13.2.2, 13.4]

Social protection programs can help the chronically poor reduce risk and protect assets during crises, through transfers of income or assets to the poor, protection against livelihood risks, and enhancement of the social status and rights of the marginalized (*medium confidence*). Existing examples underscore the need to explicitly address livelihood security and resilience in the long-term, rather than focusing on short-term disaster relief. [13.4]

Regional risks

Examples of specific regional risks across sectors are presented in Table SPM.4. Figure SPM.5 provides a synthesis of sectoral risks for several regions, based on the expert judgment of assessment authors. Risks are estimated for the era of climate responsibility (here, for 2030-2040) and for the era of climate options (here, for 2080-2100) under different levels of global average warming (about +2 or +4°C global average warming above preindustrial in 2080-2100). Risks are summarized sector by sector, reflecting the overall structure of the WGII report (Part A).

[INSERT TABLE SPM.4 HERE
Table SPM.4: Examples of regional risks that increase with increasing level of climate change. Examples of potential positive impacts are also given. Risks increasing moderately or severely from now until the 2040s, which can be considered an era of climate responsibility, are described, in addition to risks increasing from ~2050 through the end of the 21st century, which can be considered to represent an era of climate options. For risks increasing in both the era of climate responsibility and the era of climate options, the potential for proactive adaptation to reduce the risks is characterized as low or high, with detail provided on adaptation issues and prospects. Risks increasing in the era of climate options can generally be reduced through globally effective mitigation occurring during the era of climate responsibility and the era of climate options. Increasing risks in the era of climate responsibility are generally difficult to reduce substantially through mitigation, even with globally effective mitigation. They can be managed through vulnerability reduction, adaptation, and transformations that promote climate-resilient development pathways.]

[INSERT FIGURE SPM.5 HERE
Figure SPM.5: Estimated risk from climate change to selected sectors and systems in Africa (A), Europe (B), and North America (C), for different time frames (2030-2040 and 2080-2100), under two levels of global average warming above preindustrial (2°C and 4°C) and different assumptions about adaptation to manage these risks. Levels of risk and of adaptation are differentiated by colored shading, ranging from high adaptation to low adaptation. Estimated risks rely on expert judgments. The risk categories reflect the overall structure of Part A of the WGII AR5. [Figures 22-7 and 26-6]]

C.ii. Key and Emergent Risks

Key risks are potential adverse consequences for humans and social-ecological systems due to the interaction of climate-related physical hazards with vulnerabilities of societies and systems exposed. Risks are considered “key” due to high physical hazard or high vulnerability of societies and systems exposed, or both. [Box 19-2]

Key risks identified with *high confidence* include the following. [19.5.1, 19.6.2]

- Increased food insecurity from local conditions (e.g., adverse changes in rainfall patterns, limited alternative sources of income for some affected households) and regional and national conditions (e.g., breakdown of food distribution and storage processes).

- Dispossession of land, including alteration of rural inhabitants' coping and adaptation processes, from shifts in energy policies and global markets.
- Loss of livelihoods due to changes in climatic conditions and socioeconomic structures affecting people living in low-lying coastal zones and people engaged in rain-fed agriculture in developing and economies-in-transition countries.
- Increasing morbidity, mortality, and infrastructure failure as well as new systemic risks (e.g., risk of heat stress as a result of power shortages during extreme events) affecting urban areas in developed and developing countries.
- Increase in disease burden from the interaction of changes in physical climate conditions (e.g., increasing temperatures) with vulnerability (e.g., due to an aging population).
- Key risks associated with global mean temperature increase >4°C relative to preindustrial include exceedance of human physiological limits in some locations and nonlinear earth system responses. See Box SPM.5.

Interactions among climate change impacts in various sectors and regions, and human vulnerability and adaptation in other sectors and regions, as well as interactions between adaptation and mitigation actions present a variety of emergent risks (*high confidence*). [19.3.2]

- The risk of severe harm and loss due to climate-change-related hazards and various vulnerabilities is particularly high in large urban and rural areas in low-lying coastal zones. These areas, many characterized by increasing populations, are exposed to multiple hazards and potential failures of critical infrastructure.
- The risk of climate change to human systems is increased by loss of ecosystem services (e.g., water and air purification, protection from extreme weather events, preservation of soils, recycling of nutrients, pollination of crops), which are supported by biodiversity.
- In some water-stressed regions, groundwater stores that have historically acted as buffers against climate change impacts are being depleted, with adverse consequences for human systems and ecosystems, whilst at the same time climate change may directly increase or decrease regional groundwater resources.
- Climate change adversely affects human health, increasing exposure and vulnerability to other stresses, for example by altering prevalence and distribution of weather- and climate-sensitive diseases, increasing injuries and fatalities from extreme weather events, and eroding mental health following population displacement.
- Spatial convergence of impacts across sectors creates impact hotspots involving new interactions (Fig. SPM.6).

[INSERT FIGURE SPM.6 HERE
Figure SPM.6: Some salient examples of multi-impacts hotspots identified in this assessment. [Figure 19-2]]

Emergent risks also arise from indirect, trans-boundary, and long-distance impacts of climate change, sometimes mediated by the adaptive responses of human populations (*high confidence*). [19.4.1, 19.4.2]

- Increasing prices of food commodities on the global market due to local climate impacts, sometimes in conjunction with demand for biofuels, decrease food security and exacerbate malnutrition in distant locations.
- Climate change will pose significant consequences for migration flows at particular times and places, creating risks as well as benefits for migrants and for sending and receiving regions and states.
- The possible effect of climate change on conflict and insecurity has the potential to become a key risk because the magnitude of the influence of climate variability on security reported in most studies is large.
- Shifting species ranges in response to climate change adversely affect ecosystem function and services while presenting new challenges to conservation efforts. Where range shifts cannot track climatic changes, species are at risk of eventual extinction.

Under any plausible scenario for mitigation and adaptation, some degree of risk from residual damages is unavoidable (*very high confidence*). Assessments of stringent mitigation scenarios suggest that they can potentially avoid one half of the aggregate economic impacts that would otherwise accrue by 2100, and between 20-60% of the physical impacts, depending on sector and region. [19.7.1, 19.7.2]

Table SPM.5 presents specific examples of the hazards/stressors, key vulnerabilities, key risks, and emergent risks identified in the report. Box SPM.6 integrates expert judgments about risks under the reasons for concern framework.

[INSERT TABLE SPM.5 HERE

Table SPM.5: A selection of the hazards/stressors, key vulnerabilities, key risks, and emergent risks identified in the report. The examples underscore the complexity of risks determined by various climatic hazards, non-climatic stressors, and multifaceted vulnerabilities. The examples show that underlying phenomena, such as poverty or insecure land-tenure arrangements, demographic changes, or tolerance limits of species and ecosystems that often provide important services to vulnerable communities, generate the context in which climate-change-related harm and loss can occur. The examples illustrate that current global megatrends (e.g., climate change, urbanization, demographic changes), in combination and in specific development contexts (e.g., in low-lying coastal zones), can generate new systemic risks that go far beyond existing adaptation and risk management capacities, particularly in highly vulnerable regions. [Table 19-3]]

_____ START BOX SPM.5 HERE _____

Box SPM.5. Consequences of >4°C Temperature Increase

Projections of climate change impacts at 4°C global mean temperature increase above preindustrial indicate large impacts for physical, biological, and human systems and, in turn, large aggregate impacts for society and the global economy (*high confidence*). Global-mean surface temperatures for 2081–2100 (relative to early industrial, 1886–1905) for RCP 6.0 and 8.5 will *likely* be in the 5–95% range of the CMIP5 climate models, i.e., 2.0°C–3.9°C (RCP6.0), 3.3°C–5.5°C (RCP8.5).

For 4°C global mean temperature increase above preindustrial, the effects of climate change on water resources and ecosystems are projected to become dominant over other drivers such as population increases and land use change (*medium confidence*). Widespread coral reef mortality is projected (*high confidence*). Agricultural production is expected to decline in mid to high latitudes once local temperature rise exceeds 3°C (and for lower temperature rise in the tropics), corresponding to a global temperature rise below 4°C (*medium confidence*). Beyond 4°C there is high risk of marked yield loss even at high latitudes (*medium confidence*). Extreme heat waves such as that experienced in Russia in 2010 can become typical of a normal summer for a 4°C increase (*high confidence*). Sea-level rise in a 4°C world could result in the inundation of many small island states (*high confidence*). Emerging risks include exceedance of human physiological limits in some areas for a global temperature rise of 7°C (*medium confidence*).

Sub-Saharan Africa is identified as a multi-impacts hotspot in a 4°C world, with risks of increases in hunger and disease, and of loss of ecosystem function (*high confidence*). A 4°C increase would be expected to result in non-linear earth system responses, such as (1) eventual, irreversible loss of the Greenland Ice Sheet (*high confidence*) and (2) terrestrial carbon loss due to climate-carbon cycle feedback releasing CO_2 or CH_4 (*very likely*), which would accelerate climate change further. There would also be an increased chance of triggering the collapse of the West Antarctic Ice Sheet.

[12.4, 12.5, 19.4.3, 19.5.1, 19.6.3, 19.7.5, 23.4.1, WGI AR5 SPM, 2.4.3, 8.5.3, 12.4.1, Chapter 6, Table 13.5]

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Box SPM.6. Anthropogenic Interference with the Climate System

Anthropogenic interference with the climate system is occurring. [WGI AR5 SPM, 10.3-10.6] The impacts of climate change[1] are already widespread and consequential. [18.3-18.6] Determining whether anthropogenic interference is dangerous involves judgments about risks.

The IPCC assesses scientific and technical understanding of risks and the range of possible outcomes. It also assesses understanding of how risks are perceived, as well as methods for incorporating different value systems in decisionmaking. The IPCC cannot, however, make a determination of the level of anthropogenic interference that is dangerous.

[INSERT FOOTNOTE 1: See Box SPM.1 for description of differing usage of the term “climate change” in IPCC and UNFCCC.]

Assessment of existing frameworks pertinent to Article 2 of the UNFCCC has led to evaluations of risk being updated in light of the advances since AR4, including SREX and the current report's discussions of vulnerability, human security, and adaptation. The management of key and emergent risks of climate change and reasons for concern includes (i) mitigation that reduces the likelihood of physical impacts and (ii) adaptation that reduces the vulnerability and exposure of societies and ecosystems to those impacts. Many of the key vulnerabilities, key risks, and emergent risks identified in this report reflect differential vulnerability between groups due to, for example, age, wealth, or income status, and deficiencies in governance, which are particularly important in assessing risk from extreme events and risk associated with the distribution of impacts. [19.6.1, 19.6.3, 19.7]

Impacts of climate change have now been documented globally, covering all continents and the ocean (*high confidence*; Table SPM.1). The degree to which projected damages are now manifest, or the detection of stronger early warning signals for expected impacts, can contribute to a more comprehensive risk assessment for dangerous anthropogenic interference with the climate system. [18.6.2]

Updating of the reasons for concern (Box SPM.6 Figure 1) leads to the following assessment:

- Unique human and natural systems tend to have very limited adaptive capacity, and hence climate change impacts would outpace adaptation for many species and systems if a global temperature rise of 2°C over preindustrial levels were exceeded (*high confidence*). [18.6.2, 19.6.3]
- The overall risk from extreme events due to climate change has not changed significantly since AR4, but there is higher confidence in the attribution of some types of extreme events to human activity and in the assessment of the risk from extreme events in the coming decades. In addition, there is a new appreciation for the importance of exposure and vulnerability, in both developed and developing countries, in assessing risk associated with extreme events. [18.6.2, 19.6.1, 19.6.3]
- Risk associated with the distribution of impacts is generally greatest in low-latitude, less developed areas, but because vulnerability is unevenly distributed within countries, some populations in developed countries are highly vulnerable to warming of less than 2°C, as noted in AR4 (*high confidence*). [19.6.3]
- Globally aggregated risk is underestimated because it does not include many non-monetized impacts, such as biodiversity loss, and because it omits many known impacts that have only recently been quantified, such as reduced labor productivity (*high confidence*). In addition, aggregated estimates of costs mask significant differences in impacts across sectors, regions, and populations (*very high confidence*). The overall assessment of aggregate risk and confidence in that assessment has not changed since AR4. [19.6.3]
- The risk associated with large-scale singular events such as at least partial deglaciation of the Greenland ice sheet remains comparable to that assessed in AR4. [19.6.3]

[INSERT BOX SPM.6 FIGURE 1 HERE
Box SPM.6 Figure 1: The dependence of risk associated with reasons for concern (RFCs) about climate change, updated based on expert judgment in this assessment. The color scheme indicates the additional risk due to climate change (with white to purple indicating the lowest to highest level of risk, respectively). Purple color, introduced here for the first time, reflects the assessment that unique human and natural systems tend to have very limited adaptive capacity. [Figure 19-5]]

_____ END BOX SPM.6 HERE _____

D) BUILDING RESILIENCE THROUGH MITIGATION, ADAPTATION, AND SUSTAINABLE DEVELOPMENT

D.i. Climate-resilient Pathways and Transformation

Climate-resilient pathways for development are rooted in iterative processes. These processes identify vulnerabilities to climate change impacts and take appropriate steps to reduce vulnerabilities in the context of development needs and resources and to increase the options available for vulnerability reduction and coping with surprises. They involve monitoring emerging climate parameters and their implications, along with the effectiveness of vulnerability reduction efforts, and revising risk reduction responses on the basis of continuing learning. [20.2.3, 20.6.2]

Climate-resilient pathways include actions across scales (a) to reduce climate change and its impacts and (b) to assure that effective risk management and adaptation can be implemented and sustained (*high confidence* based on *high agreement, medium evidence*). Impacts of climate change avoided under a range of scenarios for mitigation of greenhouse gas emissions are potentially large and increasing over the 21st century. Since mitigation reduces the rate as well as the magnitude of warming, it also delays the need to adapt to a particular level of climate change impacts, potentially by several decades. Prospects for climate-resilient development pathways are related fundamentally to what the world accomplishes with climate change mitigation. Achieving climate-resilient development pathways benefits from attention to dynamic livelihoods, multidimensional poverty, and multifaceted impacts of climate change and climate change responses. [2.3, 2.4, 13.4, 19.7.1, 20.2, 20.3, 20.4, 20.6.1]

Estimates of global adaptation costs continue to improve but remain inconsistent in methods, sectoral coverage, purposes, and time frames. The most recent estimates suggest a range from 75 to 100 US$ billion per year globally by 2050 (*low confidence*). Important omissions from these estimates suggest the high end of this range could be much higher, and important shortcomings in the data and methods available for costing adaptation suggest the low end of this range could be substantially lower. Existing estimates of global adaptation costs could be higher if sectors such as ecosystems and tourism and socially contingent effects were included, and if developing countries' adaptation deficits were more fully taken into account. [17.3.6, 17.3.10, 17.3.11, 17.6]

Avoiding limits to adaptation will necessitate policy responses and awareness that go beyond greenhouse gas mitigation and adaptation responses alone (*medium agreement, limited evidence*). Climate-resilient pathways will often require transformations in order to assure sustainable development (*high confidence,* based on *high agreement, medium evidence*). See Box SPM.7. [2.2, 16.4, 16.6, 16.7, 20.5]

D.ii. Examples of Co-benefits, Synergies, and Tradeoffs

Responses to the risks of climate change can have implications beyond their primary objectives for the resilience of societies and systems.

Adaptation designed for one sector may interfere with the functioning of another sector, creating new risks (*high confidence*). Table SPM.6 presents potential tradeoffs among adaptation objectives. [4.3, 17.3, 19.3.2]

[INSERT TABLE SPM.6 HERE
Table SPM.6: Examples of potential tradeoffs among adaptation objectives. [Table 16-2]]

Use of the terrestrial biosphere in climate mitigation actions, such as through introduction of fast-growing tree species for carbon sequestration or the conversion of forest to biofuel plantations, may lead to negative impacts on ecosystems and biodiversity (*very high confidence*). Climate policies, such as encouraging cultivation of biofuels and payments under REDD, will result in mixed and potentially detrimental impacts on land-use and on the livelihoods of poor and marginalized people (*medium confidence*). Geoengineering approaches involving manipulation of the ocean to ameliorate climate change (e.g., purposeful nutrient fertilization, direct CO_2 injection into the deep ocean) have very large associated environmental and social consequences (*high confidence*). [3.7.2, 4.2.4, 6.4.2, 9.3.3, 13.3, 13.4, 21.5.3]

Reducing emissions of climate-altering pollutants can help reduce health impacts of climate change and simultaneously have local health co-benefits, for instance by reducing local emissions of health-damaging and climate-altering air pollutants associated with energy production and use in households and communities (*very high confidence*). In Asia as an example, development of sustainable cities with low-emissions vehicles and more trees and greenery would have a number of co-benefits including for public health. [11.9, 24.4-7]

In Europe, there are opportunities for policies that improve adaptive capacity and also help meet mitigation targets (*high confidence*). For example, some agricultural practices can potentially mitigate GHG emissions and at the same time adapt crops to increase resilience to temperature and rainfall variability. [23.8]

For Australasia, significant synergies and tradeoffs exist between mitigation and adaptation responses; interactions occur both within Australasia and between Australasia and the rest of the world (*very high confidence*). Flow-on 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*), but they remain amongst the least explored issues. [25.7.5, 25.9, Box 25-10]

Throughout North America, adaptation actions at the local level have the potential to result in synergies, conflicts, or tradeoffs with mitigation and other development actions and goals (*high confidence*). For example, reductions in emissions of greenhouse gases can yield health co-benefits, while sea walls can protect coastal properties yet may negatively affect the structure and function of coastal ecosystems. [26.8]

For small islands, energy supply and use, tourism infrastructure and activities, and coastal wetlands offer opportunities for adaptation-mitigation synergies (*medium confidence*). [29.6.2, 29.7.2, 29.8, 29.3.3]

_____ START BOX SPM.7 HERE _____

Box SPM.7. Adaptation Limits and Transformation

Limits to adaptation emerge from the interaction between climate change and biophysical and socioeconomic constraints (*high agreement, robust evidence*). See Box SPM.7 Figure 1. Some adaptation limits may be removed over time through changing values or technological advancement.

[INSERT BOX SPM.7 FIGURE 1 HERE
Box SPM.7 Figure 1: Conceptual model of acceptable, tolerable, and intolerable risks and implications for limits to adaptation. [16.2, Figure 16-1]]

Greater adaptation efforts will be required to achieve objectives if mitigation efforts are not successful in avoiding high magnitudes of climate change (*high agreement, limited evidence*). There are, however, limits to the extent to which adaptation could reduce the impacts not avoided by mitigation, and residual loss and damage may occur despite adaptive action. The greater the magnitude of climate change, the greater the likelihood that adaptation will encounter limits.

Transformative changes may be necessary as a response to projected climate changes (*medium confidence*). Transformation in wider political, economic, and social systems can open or close policy spaces for more resilient and sustainable forms of climate responses (*high confidence*). While transformations may be reactive, forced, or induced by random factors, they may also be deliberately created. Deliberate transformations can take place in relation to transformational adaptation, transformation to low-carbon societies, or transformations to global sustainability.

[14.1, 14.3.4, 16.2, 16.3, 16.4, 16.5, 19.6, 19.7, 20.5, 25.3, 25.4, 25.11]

_____ END BOX SPM.7 HERE _____

Table SPM.1: Observed impacts attributed to climate change with *medium* (*) or *high* (**) confidence, for physical, biological, and human systems across eight major world regions. [Tables 18-6, 18-7, 18-8, 18-9]

REGION	Freshwater Resources & Systems	Terrestrial Ecosystems, Drought, & Wildfire	Coastal & Marine Systems	Human Systems
Africa	Retreat of tropical highland glaciers in East Africa* Lake surface warming & water column stratification increases in the Great Lakes & Lake Kariba** [13.2.1, 22.3.2, 22.5.1]	Tree density decreases in Sahel & semi-arid Morocco* Climate-driven range shifts of several southern plants & animals* Increased drought in the Sahel since 1970, partially wetter conditions since 1990* [22.2.2, 22.3.2]		Decline in fruit-bearing trees in Sahel*
Europe	Retreating glaciers in the Alps** Increase in rock slope failures in Western Alps** [18.3.1]	Earlier greening, earlier leaf emergence, & fruiting in temperate & boreal trees** Increased colonization of alien plant species in Europe* Earlier arrival of migratory birds in Europe since 1970* Increasing burnt forest areas during recent decades** [4.2.4, 4.4.1]	Poleward shifts in the distributions of zooplankton, fishes, seabirds, & benthic invertebrates, & conversion of polar into more temperate & temperate into more subtropical system characteristics in Northeast Atlantic** Phenology changes & retreat of colder water plankton to north in the Northeast Atlantic, with mean poleward movement of plankton reaching up to 200–250 km per decade from 1958–2005* Atlantic cod distribution shift due to warming, interacting with regime shift & regional changes in plankton phenology in North Sea.* Decreasing abundance of eelpout in Wadden Sea** [6.3.2, Table 6-8, Figure 6-16, 18.3.3, 30.5.1]	Stagnation of wheat yields in some countries in recent decades, due to warming and/or drought*
Asia	Permafrost degradation in Siberia, Central Asia, & Tibetan Plateau** Shrinking mountain glaciers across Asia.* Increased runoff in many rivers due to shrinking glaciers in the Himalayas & Central Asia** Surface water degradation in parts of Asia partially related to climate change* Earlier timing of maximum spring flood in Russian rivers** [Box 3-1, Box 3-2, 24.4.1, 28.2.1, WGI AR5 Chapter 4.3.2-4.3.3, 10.5.3]	Changes in plant phenology & growth in many parts of Asia, particularly in the north & east* Distribution shifts of many plant & animal species, particularly in the north of Asia, generally upwards in elevation or polewards* Advance of shrubs into the Siberian tundra* [4.2.1, Box 4-1, 24.4.2, 28.2.3]	Decline in coral reefs & large seaweeds in tropical Asian & Japanese waters** Shift from sardines to anchovies in Japanese Sea* [6.3.2, Figure 16-6, 24.4.3]	
Australasia	Significant decline in late-season snow depth at four alpine sites in Australia (1957-2002)*	Climate-related changes in genetics, growth distribution, & phenology of many species (e.g., earlier emergence of butterflies, change in plant flowering dates & bird breeding times, decline in body size of passerine birds)* [Table 25-3]	Mass bleaching of corals in the Great Barrier Reef, changes in coral calcification rates, & changes in coral disease dynamics** Multiple impacts of climate change on marine ecosystems from warming oceans, although other environmental changes may play a role. Examples are growth rate increases in fishes, intertidal-invertebrate range shifts, range shifts in near-shore fishes related to kelp decline, increasing abundance of northern marine species in Tasmania, recruitment declines of rock lobster & abalone, declines in growth rate & biomass of phytoplankton, southward expansion of some tropical seabirds in Australia** [6.3.2, Box 18-3, 25.6.2, Table 25-3]	Wine-grape maturation has advanced in recent decades, partly due to warming*

REGION	Freshwater Resources & Systems	Terrestrial Ecosystems, Drought, & Wildfire	Coastal & Marine Systems	Human Systems
North America	Primarily decreasing trends in amount of water stored in spring snowpack from 1960-2002** Observed shift to earlier peak flow in snow dominated rivers in Western North America** Runoff increases in the Midwestern & Northwestern US, decreases in Southern states* [26.2.2, WGI AR5 Chapter 2.6.2]	Species distribution shifts upward in elevation & northward in latitude across multiple taxa* Phenology changes* Increases in wildfire activity, including fire frequency & duration, length of fire season, & area burned* [26.4.1, 26.4.2, Box 26-2]	Northward range shifts of Northwest Atlantic fishes in response to warming since the 1960s, with some of the shifts being correlated with the Atlantic Multidecadal Oscillation* Earlier onset of Pink Salmon migration (Alaska), collapse of Sockeye Salmon spawning migration (Fraser River, BC), due to warming** Loss of biomass of midwater fishes off California Coast** [6.3.3, 6.6.3, Table 6-8, Figure 6-16]	Direct & indirect economic impacts of climate extremes on industry through reduced supply of raw material, the production process, the transportation of goods, & the demand for certain products* [26.8]
Central & South America	Retreat of tropical Andean glaciers in Venezuela, Colombia, Ecuador, Peru, & Bolivia (1950-2000) & glaciers & ice-fields in the extra tropical Andes** Changes in extreme flows in Amazon River* Changed discharge patterns in rivers in the Western Andes due to retreating glaciers & reduced snowpack; for major river basins in Colombia, decreased discharge during the last 30-40 years** Increased stream flow in sub-basins of the La Plata River, attributed to increasing precipitation, but also to trends in land-use changes that have reduced evapotranspiration** [27.2.1, 27.3.1]		Bleaching of coral reefs in the western Caribbean near the coast of Central America** [27.3.3]	Increase in frequency & extension of malaria* Increase in agricultural yields in Southeastern South America* [27.3.4, 27.3.7]
Polar Regions	Decreasing Arctic sea ice cover in summer & reduction in glacier ice volume, due to warming* Decreasing snow cover duration across the entire Arctic* Widespread permafrost degradation, especially in the southern Arctic** Rising winter minimum flows in most sectors of the Arctic due to enhanced groundwater input due to permafrost thawing* Disappearance of thermokarst lakes due to permafrost degradation in the low Arctic. New lakes being created in areas of formerly frozen peat** [28.2.1, 28.2.3, WGI AR5 Chapter 10.5.1]	Increase in shrub cover in tundra in North America & Eurasia.** Significant advance of Arctic tree-line in latitude & altitude, due to warming, although lower pace than expected due to insect outbreaks & land-use history. Changes in breeding area & population size of subarctic birds, due to warming & shrub encroachment in the tundra* Retreating snow-bed ecosystems & tussock tundra, due to prolonged thawing season & less precipitation in the form of snow.** Increasing occurrence of ice layers in the annual snow pack due to rain-on-snow events, affecting animal populations in the tundra* Increasing plant species in the West Antarctic Peninsula & nearby islands over the past 50 years** Increasing drought in high Arctic polar deserts** Increased frequency of wildfires in conifer forest at Arctic southern fringe, due to increasing summer temperature. Tundra wildfires are increasing in frequency in the Low Arctic, due to increasing summer air temperature & subsequent surface drought* [28.2.1, 28.2.3]	Sea ice loss negatively affecting many arctic & subarctic marine non-migratory mammals (walrus, seals, whales)** Reduced growth rate & body mass, lower survival & reproductive capacity of polar bears, linked to reduced off-shore range & sea-ice loss due to warming** Reduced reproductive success of Arctic seabirds, due to earlier sea-ice break-up* Reduced thickness of foraminifera shells due to acidification of Southern Ocean waters * Declines in Antarctic krill density in the Scotia Sea by ~30% since the 1980s, due to reduced winter sea ice extent & duration* Many Southern Ocean species of seals & seabirds, e.g., penguins & albatross, negatively responding to warmer conditions* Increased coastal erosion in Arctic, due to prolonged ice-free season at shore, increased exposure to wave activity, & degrading permafrost** [6.3.4, 28.2.2, 28.2.4, 28.2.5, 28.3.4]	Impact on livelihoods of Arctic indigenous peoples* [18.4.5, Box 18-5]
Small Islands		Tropical-bird population changes in Mauritius, due to changes in rainfall* [29.3.2]	Coral bleaching near many tropical small islands** [29.3.1]	

Table SPM.2: Illustrative examples of adaptation experience, as well as approaches to reduce vulnerability and enhance 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 vulnerabilities, inequalities, and climate change come to the fore. At the same time, place-based examples illustrate how larger-level drivers and stressors shape differential risks and livelihood trajectories, often mediated by institutions.

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, wave erosion, 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, are particularly vulnerable. [15.3.4, 29.7.2]
CLIMATE INFORMATION AT THE GLOBAL SCALE: Observed: *Likely* increase in extreme sea levels since 1970, mainly caused by rising mean sea level. *Low confidence* that any reported long-term changes in tropical cyclones are robust. Projected: By the end of 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. *More likely than not* substantial increase in the frequency of the most intense tropical cyclones in some basins. [WGI AR5 2.6.3, 3.7.5, 11.3.2, Box 14.2]
CLIMATE INFORMATION AT THE REGIONAL SCALE: Observed: Regional rates of sea level change can vary significantly from the global mean. Mean significant wave height *likely* increased since the mid-1980s over much of the mid-latitude North Atlantic, the North Pacific, and the Southern Ocean. For tropical cyclones observed over the satellite era, increases in the intensity of the strongest storms in the Atlantic appear robust. Projected: For all ocean basins, tropical cyclone frequency is projected to decline or remain the same, the mean lifetime maximum intensity of tropical cyclones is projected to increase or remain the same, and cyclone-associated rainfall rates are projected to increase. In the North Atlantic and the eastern part of the North Pacific, the frequency of category 4/5 tropical cyclones is projected to increase. *Very likely* increase in the occurrence of future extreme sea level and related coastal flooding events with increasing global mean sea level, but *low confidence* in region-specific projections in storminess and storm surges. [WGI AR5 2.6.3, 3.4, 3.7, 13.7.2; Figures 3.6-3.8, 13.19; Box 14.2]
DESCRIPTION: Mangrove restoration and rehabilitation has occurred in a number of locations (Vietnam, Myanmar, Samoa, and Brazil, for example) to reduce coastal flooding risks and protect shorelines from storm surge. In Vietnam, 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. [8.3.3, 2.3.4, 15.3.4, 27.3.3, 22.4.5]
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, wave damage, and erosion. •Synergies with mitigation given that mangrove forests are sinks for carbon. •Restoration and rehabilitation can help build local knowledge, capacity, and strategies to institutionalize climate change adaptation and resilience in local planning and development. •Mangrove bioshields created from exotic species can detrimentally impact native ecosystems. [8.4.2, Box 5.4, 29.7.2, 15.3.4]

Farming practices in Africa, such as zai and integration of trees into annual cropping systems
EXPOSURE AND VULNERABILITY: Land degradation and soil infertility have negatively impacted yields in parts of Africa, such as in Zambia, Malawi, the highlands of Ethiopia, Burkina Faso, and the drylands of the Sahel. Soil erosion, soil compaction due to livestock trampling, and low soil water holding capacity reduce plant growth. [7.5.2, Table 9-6, Box 22-4]
CLIMATE INFORMATION AT THE GLOBAL SCALE: Observed: Increase in globally averaged near surface temperatures since 1900, with warming particularly marked since the 1970s. *Very likely* decrease in the overall number of cold days and nights and increase in the overall number of warm days and nights, on the global scale between 1951 and 2010. *Medium confidence* that the length of warm spells, including heat waves, has increased globally since 1950. *Medium confidence* in global precipitation change over land since 1950. *Likely* increase in the number of heavy precipitation events in more regions than the number has decreased since 1950. *Low confidence* in any observed large-scale trends in drought. Projected: For RCP 4.5, 6.0, and 8.5, global mean surface air temperatures are projected to at least *likely* exceed 2°C with respect to preindustrial by 2100. *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global temperature increases, for events defined as extremes on both daily and seasonal timescales. *Virtually certain* increase in global precipitation as global mean surface temperature increases. Regional to global-scale projections of soil moisture and drought remain relatively uncertain. For short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 2.4, 2.5.1, 2.6.1, 2.6.2, 12.3.1, 12.4.1, 12.4.3, 12.4.5; Figures 2.28, 12.2, 12.5]

CLIMATE INFORMATION AT THE REGIONAL SCALE:

Observed: Increase in frequency of warm days and nights in northern and southern part of continent and decrease in frequency of cold days and nights in southern part of continent.
Overall increase in dryness and modest increases in rainfall over most of equatorial Africa and the Red Sea coast (*medium confidence*).
Projected: *Likely* increase in warm days and decrease in cold days in all regions of Africa (*high confidence*). Increase in warm days largest in summer and fall (*medium confidence*).
Likely more frequent and/or longer heat waves and warm spells in Africa (*high confidence*).
[22.2.2; SREX Tables 3-2, 3-3]

DESCRIPTION:

Zai uses small pits dug manually during the dry season, combined with contour stone bunds to slow runoff. Animal manure or compost is placed in each pit. The pits facilitate water infiltration and concentrate runoff water, and the applied organic matter improves soil nutrient status and attracts termites, which positively affect soil structure. The practice can also improve tree growth amid crop rows, and trees, especially nitrogen-fixing varieties, can be integrated as an independent strategy. Trees reduce crop exposure to wind and heavy rainfall and improve moisture retention and rainwater capture. Factors that have enabled farmer-managed natural regeneration include in southern Niger devolving tree ownership from the state to the farmer, as well as community-based efforts involving partnerships of farmers and NGOs.
[7.5.2, Table 9-6, Box 22-4, 15.3.4]

BROADER CONTEXT:

- Both techniques can improve yields, water retention, food security, and income generation, also reversing land degradation.
- Tree growth, through production of fruit, animal fodder, or fuelwood, can expand livelihood options and allow diversification, thereby enhancing resilience.
- Zai is a very labor-intensive technique, which can be expedited through use of animal-drawn implements.
- Farmer-managed natural regeneration has been paired with other low-cost behavioral actions, for example in Ethiopia, aiming to reverse ecosystem degradation and promote reforestation with benefits for carbon sequestration.

[7.5.2, Table 9-6, Box 22-4, 15.3.4, 17.4.1]

Adaptive approaches to flood defense in Europe

EXPOSURE AND VULNERABILITY:

In some countries, a high percentage of the population is exposed to flooding. Exposed assets and infrastructure represent a substantial fraction of national GDPs.
[Box 5-3]

CLIMATE INFORMATION AT THE GLOBAL SCALE:

Observed: *Likely* increase in extreme sea levels since 1970, mainly caused by rising mean sea level.
Likely increase in the number of heavy precipitation events in more regions than the number has decreased since 1950.
Projected: *Very likely* that the rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971-2010 for all RCP scenarios.
For short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms.
[WGI AR5 2.6.2, 3.7.5, 12.4.5, 13.5.1, Table 13.5]

CLIMATE INFORMATION AT THE REGIONAL SCALE:

Observed: Increased heavy wintertime precipitation since the 1950s in some areas of Northern Europe (*medium confidence*).
Increased heavy precipitation since the 1950s in some parts of west-central Europe and European Russia, especially in winter (*medium confidence*).
Isostasy and decreasing sea level in Scandinavia.
Projected: Overall precipitation increase in Northern Europe and decrease in Southern Europe (*medium confidence*).
Increased extreme precipitation in Northern and Atlantic regions of Europe during all seasons, and in Central Europe except in summer (*high confidence*). Annual increases of intense precipitation days over the Mediterranean region.
Storm activity over the North Atlantic *likely* to increase and extend farther downstream into Europe, and to decrease on both the north and south flanks, especially over the Mediterranean (*medium confidence*).
Likely reduction in the occurrence of Northern Hemisphere extratropical storms, although the most intense storms reaching Europe *likely* to increase in strength. An increase in the North Atlantic Oscillation *likely* to increase the number of wintertime storms heading into Northern Europe and the average intensity of precipitation per storm.
[23.2.2; WGI AR5 Box 14.3; SREX Table 3-2]

DESCRIPTION:

Several governments have made ambitious efforts to address flood risk over the coming century. In the Netherlands, government recommendations include "soft" measures preserving land from development to accommodate increased river inundation; raising the level of lakes to ensure continuous freshwater supply; restoring natural estuary and tidal regimes; maintaining flood protection through beach nourishment; and ensuring necessary political-administrative, legal, and financial resources. The plan is estimated to cost €2.5 to 3.1 billion a year through 2050, 0.5% of the current Dutch annual GNP. The British government has also developed extensive adaptation plans to adjust and improve flood defenses for the protection of the Thames estuary and the city of London from future storm surges and river flooding. Pathways for different adaptation options and decisions depending on eventual sea level rise have been analyzed.
[Box 5-3, 23.7.1]

BROADER CONTEXT:

- The Dutch plan is considered a paradigm shift, addressing coastal protection by "working with nature" and providing "room for river." The concept of creating space for water and integrating water management approaches with goals of environmental protection is an essential component of integrated water management.
- The British plan incorporates iterative, adaptive decisions depending on the eventual sea level rise.
- The large infrastructure project of the Thames flood defense barrier involved public-private partnerships.
- In cities in Europe and elsewhere, the importance of having strong political leadership or government champions to drive the initial development of climate adaptation plans has been noted.

[Box 5.3, 23.7.1, 17.5.3, 8.5.3, 23.7.4, 23.7.2]

Relocation of agricultural industries in Australia

EXPOSURE AND VULNERABILITY:
Crops sensitive to changing patterns of rainfall, water availability, and temperature.
[7.5.2]

CLIMATE INFORMATION AT THE GLOBAL SCALE:
Observed: Increase in globally averaged near surface temperatures since 1900, with warming particularly marked since the 1970s.
Very likely decrease in the overall number of cold days and nights and increase in the overall number of warm days and nights, on the global scale between 1951 and 2010.
Medium confidence that the length of warm spells, including heat waves, has increased globally since 1950.
Medium confidence in global precipitation change over land since 1950.
Likely increase in the number of heavy precipitation events in more regions than the number has decreased since 1950.
Low confidence in any observed large-scale trends in drought.
Projected: For RCP 4.5, 6.0, and 8.5, global mean surface air temperatures are projected to at least *likely* exceed 2° C with respect to preindustrial by 2100.
Virtually certain that, in most places, there will be more hot and fewer cold temperature extremes as global temperature increases, for events defined as extremes on both daily and seasonal timescales.
Virtually certain increase in global precipitation as global mean surface temperature increases.
Regional to global-scale projections of soil moisture and drought remain relatively uncertain.
For short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms.
[WGI AR5 2.4, 2.5.1, Figure 2.28, 2.6.1, 2.6.2, 12.3.1, 12.4.1, Figure 12.2, Figure 12.5, 12.4.3, 12.4.5]

CLIMATE INFORMATION AT THE REGIONAL SCALE:
Observed: Mean temperature increase of 0.9°C per decade over Australia since 1911 (*very high confidence*).
Cool extremes rarer and hot extremes more frequent and intense over Australia and New Zealand (*high confidence*).
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*).
Significant increases in annual intensity of heavy precipitation in recent decades for sub-daily events in Australia (*high confidence*).
Projected: Further warming of Australasia this century *virtually certain*, greatest over inland areas and least in coastal areas.
Hot days and nights more frequent and cold days and nights less frequent during the 21st century in Australia and New Zealand (*high confidence*).
Annual decline in precipitation over southwestern Australia (*high confidence*) and in southern Australia (*medium confidence*). Reductions strongest in the winter half-year (*high confidence*).
Increase in intensity of rare daily rainfall extremes (*high confidence*) and of annual daily extremes (*medium confidence*) in Australia and New Zealand.
Drought occurrence to increase in Southern Australia (*high confidence*).
Snow depth and snow area to decline in Australia (*very high confidence*).
Freshwater resources projected to decline in the highly populated southeast and the far southwest of Australia.
[25.5.1, Table 25-1]

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 perceptions of future change. There have been new investments in grapes in Tasmania and switching from grazing to cropping in South Australia. Adaptive movement of crops has also occurred elsewhere, such as in China.
[7.5.2, Table 9-6, 25.7.2, Box 25-5]

BROADER CONTEXT:
- Considered transformational adaptation in response to impacts of climate change.
- Positive or negative implications for communities in origin and destination regions, with substantial changes required in transport chains, inputs, management, or growing contracts.
- Some decisions run across scales and include many stakeholders, with comprehensive regional assessments across enterprises and economic and resource outcomes needed.

[7.5.2, 25.7.2, Box 25-5]

Table SPM.3: Entry points, strategies, measures, and options for managing the risks of climate change. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples given can be relevant to more than one category.

Entry Point	Category		Examples		Chapter Reference(s)
Vulnerability reduction through development and planning	Forms of sectoral integration	Human development	Specific measures	Low regrets options to reduce structural inequalities: improved access to education, nutrition, health facilities, energy, safe settlement structures, social support structures; reduced gender inequality and marginalization in other forms.	13.1.2, 13.3.1, 13.4.1, 13.4.2, 22.3.1
		Poverty alleviation		Insurance schemes, social protection programs, disaster risk reduction. Improved access to and control of local resources, land tenure, and storage facilities. Low regrets options to reduce structural inequalities.	13.1.2, 13.3.1, 13.3.2, 13.4.1
		Livelihood security		Income and asset diversification. Improved infrastructure. Access to technology and decision-making fora, enhanced agency.	13.1.1, 13.3.1, 13.4.1
		Disaster risk reduction and management		Early warning systems.	11.7.3, 22.4.5, 26.9.1
		Ecosystem management		Maintaining wetlands and urban green spaces, coastal afforestation.	8.3.3, Box 8.1, 15.3.1, Box CC-EA
		Spatial or land-use planning		Provisioning of adequate housing, infrastructure, and services. Managing development in flood prone and other high risk areas.	8.1.4, 8.4.3, 8.5.3
Adaptation	Structural/ concrete	Engineered	Specific options	Sea walls, water storage, improved drainage, beach nourishment, flood shelters. Improved infrastructure.	14.3.1, Table 14-2
		Technological		New crop and animal varieties, efficient irrigation and water use, hazard mapping and monitoring, early warning systems, home insulation.	14.3.1, Table 14-2
		Ecosystem-based		Wetland reestablishment, reestablishment of floodplains, bushfire fuel-reduction actions.	14.3.1, Table 14-2
		Services		Social safety nets, food banks, vaccination programs, municipal services.	14.3.1, Table 14-2
	Institutional	Economic	Specific options	Financial incentives, insurance and other risk spreading.	13.3.2, 14.3.2, Table 14-2
		Laws and regulations		Land zoning laws, building standards, easements.	14.3.2, Table 14-2
		Government policies and programs		National and local adaptation plans, urban upgrading programs, municipal water conservation programs, disaster planning and preparedness.	14.3.2, Table 14-2
	Social	Educational	Specific options	Awareness raising, extension services.	14.3.3, Table 14.2
		Informational		Hazard mapping and monitoring, early warning, community support groups.	14.3.3, Table 14-2
		Behavioral		Household preparation, evacuation planning, retreat and migration, water conservation, storm drain clearance.	14.3.3, Table 14-2
Transformation	Spheres of change	Practical	Specific strategies	Social and technical innovations, behavioral shifts, or institutional and managerial changes that produce measurable outcomes.	20.5.2
		Political		Changes in the political, social, cultural, and ecological systems or structures that currently contribute to risk and vulnerability or impede practical transformations.	20.5.2
		Personal		Changes in individual and collective assumptions, beliefs, values, and worldviews that influence climate change responses.	20.5.2
Mitigation	See WGIII AR5.				

Table SPM.4: Examples of regional risks that increase with increasing level of climate change. Examples of potential positive impacts are also given. Risks increasing moderately or severely from now until the 2040s, which can be considered an era of climate responsibility, are described, in addition to risks increasing from ~2050 through the end of the 21st century, which can be considered to represent an era of climate options. For risks increasing in both the era of climate responsibility and the era of climate options, the potential for proactive adaptation to reduce the risks is characterized as low or high, with detail provided on adaptation issues and prospects. Risks increasing in the era of climate options can generally be reduced through globally effective mitigation occurring during the era of climate responsibility and the era of climate options. Increasing risks in the era of climate responsibility are generally difficult to reduce substantially through mitigation, even with globally effective mitigation. They can be managed through vulnerability reduction, adaptation, and transformations that promote climate-resilient development pathways.

---------------- LEGEND ----------------

ERA & ADAPTATION POTENTIAL	Risk for current (C) and hypothetical fully adapted (A) state. Color scheme depicts the additional risk due to climate change. White to red indicates lower and higher levels of risk, respectively. The vertical axis of each bar represents the level of climate change (T). The horizontal blue line indicates the level of climate change at the end of the era of climate responsibility.		
T C A	A risk increasing moderately as early as the era of climate responsibility (now through the 2040s), which can be reduced substantially with proactive adaptation.	T C A	A risk increasing moderately as early as the era of climate responsibility (now through the 2040s), which will be difficult to reduce substantially even with proactive adaptation.
T C A	A risk increasing moderately or severely during the era of climate options (~2050 through the end of the 21st century), which can be reduced substantially with proactive adaptation. The risk can generally be reduced through globally effective mitigation occurring during the era of climate responsibility and the era of climate options.	T C A	A risk increasing moderately or severely during the era of climate options (~2050 through the end of the 21st century), which will be difficult to reduce substantially even with proactive adaptation. The risk can generally be reduced through globally effective mitigation occurring during the era of climate responsibility and the era of climate options.
T C	A risk increasing moderately as early as the era of climate responsibility (now through the 2040s), for which potential for risk reduction via proactive adaptation was not assessed.	T C	A risk increasing moderately or severely during the era of climate options (~2050 through the end of the 21st century), for which potential for risk reduction via proactive adaptation was not assessed.

CLIMATE DRIVERS	Where particular climate driver(s) are especially relevant for an assessed risk, they are indicated via the symbols below.						
	Average temperature		Extreme temperature		Precipitation		Extreme precipitation
CO_2	CO_2 concentration & ocean acidification		Damaging cyclone		Snow cover		Sea level

REGION	RISKS — FRESHWATER RESOURCES AND SYSTEMS	Climate Driver(s)	Era & Adaptation Potential	Adaptation Issues/Prospects	Chap. Ref.
Europe	Climate change is *likely* to further increase coastal and river flood risk and, if unabated, will substantially increase flood damages (monetary losses and people affected).		C A C A	Adaptation can prevent most of the projected damages (*high confidence*).	23.3.1, 23.5.1, 23.7.1, 23.8.3
Asia	Shrinking of glaciers in Central Asia and the Himalayas is projected to affect water resources in downstream river catchments. Population growth and increasing demand arising from higher standards of living could worsen water security in many parts of Asia and affect many people in the future.		C A C A	Water saving technologies and changing to drought tolerant crops have been found to be successful adaptation options in the region.	24.4.1, 24.9.3
Australasia	Systematic constraints on water resource use in southern Australia, driven by rising temperatures and reduced cool-season rainfall (*high confidence*).		C A	Integrated responses encompassing management of supply, recycling, water conservation, and increased efficiency across all sectors are available but face implementation constraints.	25.2, 25.5.1, Box 25-2

	Increased frequency and intensity of flood damage to settlements and infrastructure in Australia and New Zealand, driven by increasing extreme rainfall although the amount of change remains uncertain (*high confidence*).			In many locations, continued reliance on increased protection alone would become progressively less feasible.	Table 25-1, 25.4.2, 25.10.3, Box 25-8
North America	Throughout North America, it is *very likely* that the 21st century will witness decreases in water quality, and increases in flooding and droughts under climate change, with these impacts exacerbated by other anthropogenic drivers. It will also witness decreases in water supplies for urban areas and irrigation in some areas of North America, with confounding effects of development.				26.3, 26.8
Central and South America	For regions already vulnerable in terms of water supply, such as the semi-arid zones in Chile-Argentina, North Eastern Brazil, and Central America and the tropical Andes, glacier retreat and a reduction in water availability due to expected precipitation reduction and increased evapotranspiration demands are expected, affecting water supply for large cities, small communities, hydropower generation, and the agriculture sector.			Current practices to reduce the mismatch between water supply and demand could be used to reduce future vulnerability.	27.3.1, 27.6.1

REGION	RISKS — TERRESTRIAL ECOSYSTEMS, DROUGHT, & WILDFIRE	Climate Driver(s)	Era & Adaptation Potential	Adaptation Issues/Prospects	Chap. Ref.
Africa	Many fragile terrestrial and aquatic ecosystems are implicitly or explicitly water dependent. Impacts of climate change will be superimposed onto already water-stressed catchments with complex land uses, engineered water systems, and a strong historical socio-political and economic footprint (*high confidence*).				22.3.2, 22.3.3
Europe	Changes in habitats and species will result in local extinction (*high confidence*) and continental scale shifts (*low/medium confidence*). Increasing local loss of native species and extinction of species across most sub-regions of Europe by 2050 (medium emissions) with economic development and land-use change. Introduction and expansion of invasive species, especially those with high migration rates, from outside Europe will increase with climate change (*medium confidence*).				23.4.4, 23.6.4, 23.6.5, 23.10, Table 23.2
	Climate change will increase damage to forests from pests and diseases in all sub-regions (*high confidence*), from wildfires in Southern Europe (*high confidence*), and from storms (*low confidence*).				23.4.4
Asia	Terrestrial systems are under increasing pressure from both climatic and non-climatic drivers. The projected changes in climate will impact vegetation and increase permafrost degradation during the 21st century (*high confidence*). The largest changes are expected in cold northern and high-altitude areas, where boreal and subalpine trees will *likely* invade treeless arctic and alpine vegetation, and evergreen conifers will *likely* invade deciduous larch forest.				24.2.2, 24.4.2, 24.4.3, 24.9.3
Australasia	Loss of montane ecosystems and some endemic species in Australia, driven by rising temperatures, increased fire risk and drying trends (*high confidence*).			Fragmentation of landscapes, limited dispersal, and evolutionary capacity limit adaptation options.	25.6.1
	Increased damages to ecosystems and settlements, economic losses, and risks to human life from wildfires in most of southern Australia and many parts of New Zealand, driven by drying trends and rising temperatures (*high confidence*).			Building codes, design standards, local planning mechanisms, and public education can assist with adaptation and are being implemented in regions that have experienced major events.	25.2, 25.6.1, 25.7.1, Box 25-6
North America	A global increase of 2°C would have widespread adverse impacts on many ecosystems, *likely* reducing biodiversity and ecosystem services (*high confidence*).				26.4
Central and South America	Continued climate change together with land use change and fire activity could cause much of the Amazon forest to transform abruptly to more open, dry-adapted ecosystems, and in doing so, put a large stock of biodiversity at elevated risk and create a large new net greenhouse gas source to the atmosphere (*low confidence*).			Rigorously applied adaptation measures could lower the risk of abrupt change in the Amazon, as well as the impacts of that change (*medium confidence*).	4.2.2, 4.2.4, 4.3.3, Box 4-3, Box 4-4

Polar Regions	Continued climate change could push the boreal-arctic system across a tipping point in this century and cause an abrupt transformation of the ecology and albedo of this region, as well as the release of greenhouse gases from thawing permafrost and burning forests (*low confidence*).			Adaption measures will be unable to prevent substantial change in the boreal-arctic system (*high confidence*).	4.2, 4.3.3, Box 4-3, Box 4-4
REGION	**RISKS — COASTAL & MARINE SYSTEMS**	**Climate Driver(s)**	**Era & Adaptation Potential**	**Adaptation Issues/Prospects**	**Chap. Ref.**
Africa	Impacts of climate change, mainly through sea level rise, combined with other extreme events (such as high tide levels and high storm swells) have the potential to threaten coastal zones, particularly coastal towns (*high confidence*).				22.3.2, 22.3.4, 22.3.7
Europe	Costs of adapting dwellings or upgrading coast defense will increase under all scenarios (*high confidence*).				23.3.2, 23.6.5, 23.7.3
Asia	In the Asian Arctic, rising sea levels will interact with projected changes in permafrost and the length of the ice-free season to cause increased rates of coastal erosion (*high agreement*, *medium evidence*).				24.4.3
Austral-asia	Significant change in community structure of coral reef systems in Australia, driven by increasing sea-surface temperatures and ocean acidification (*high confidence*).	CO_2		The natural ability of reefs to adapt to projected changes is limited.	Box CC-CR, 25.6.2, 30.5
	Widespread damages to coastal infrastructure and low-lying ecosystems in Australia and New Zealand if sea level rise exceeds 1m (*high confidence*). Risks from sea level rise *very likely* continue to increase beyond 2100 even if temperatures are stabilized.			Managed retreat is a long-term adaptation strategy for human systems but options for some ecosystems are limited due to rapidity of change & lack of suitable space for inland migration.	WGI AR5 13; Box 25-1, 25.6, 25.4.2
Polar Regions	Shifts in the timing of seasonal biomass production could disrupt matched phenologies in food webs, leading to decreased abundance of high latitude marine organisms (*medium confidence*).				28.2.2, 28.3.2
REGION	**RISKS — HUMAN SYSTEMS**	**Climate Driver(s)**	**Era & Adaptation Potential**	**Adaptation Issues/Prospects**	**Chap. Ref.**
Africa	Spatial convergence of impacts in different sectors creates impact “hotspots” involving new interactions, for example, in Sub-Saharan Africa where global warming at the high end of the range projected for this century, i.e., more than 4°C above preindustrial levels, would be especially disruptive, resulting in high risk of reduced extent of croplands, reduced length of the growing season, increased hunger, and increased malaria transmission.				19.3.2
	Temperature rise and a reduction in growing season length by mid-century are expected to significantly reduce crop productivity with strong adverse effects on food security. New challenges to food security are emerging as a result of strong urbanization trends on the continent and increasingly globalized food chains, which require better understanding of the multi-stressor context of food and livelihood security.				22.3.4
Europe	Increasing heat wave mortality across most sub-regions of Europe by 2050 (medium emissions) with economic development and land-use change. Particularly in Southern Europe, increased frequency and intensity of heat waves (*high confidence*) will have adverse implications for health, agriculture, energy production, transport, tourism, labor productivity, and built environment (*medium confidence*).				23.2.2, 23.5.1, Tables 23-4, 23-5
	Climate warming will decrease space heating demand and increase cooling demand (*high confidence*), with income growth driving the largest part of this increase from 2000-2050 (especially in eastern regions) (*medium confidence*). Climate change will increase problems associated with overheating in domestic housing.			Energy efficient buildings and cooling systems as well as demand-side management will reduce future energy demands.	23.3.2, 23.3.4
	Climate change will increase yields in Northern Europe (*medium confidence*) but decrease cereal yields in Southern Europe (*high confidence*).				23.4.1, 23.4.2, 23.5.1

	Climate change will decrease hydropower production from reductions in rainfall in all sub-regions except Scandinavia (*high confidence*). Climate change will inhibit thermal power production during summer (*medium confidence*).			Plant modifications and operational changes can reduce adverse impacts.	23.3.4
	Increasing damage of cultural buildings and loss of cultural landscapes across most sub-regions by 2050 (medium emissions). Climate change and sea level rise will damage cultural heritage and iconic places such as Venice (*medium confidence*). Some cultural landscapes will be lost forever (*low/medium confidence*).				23.5.4, Table 23-5
Asia	Impacts of climate change on food production and security will vary by region with many regions experiencing productivity decline (*medium confidence*), e.g., in the case of rice production, with lower yields due to shorter growing periods and heat-induced sterility. Some regions are already near the critical temperature threshold. In parts of Asia, increases in flood and drought will exacerbate rural poverty due to negative impacts on rice crops and increases in food prices and costs of living (*high confidence*).			There are many potential adaptation strategies such as crop breeding, but research on their effectiveness is limited.	24.4.4, 24.4.6
	More frequent and intense heat-waves will increase mortality and morbidity in vulnerable groups. Increases in heavy rain and temperature will increase the risk of diarrheal diseases and malaria (*high confidence*).				24.4.6
Austral-asia	Increasing morbidity, mortality, and infrastructure damages during heat waves in Australia, resulting from increased frequency and magnitude of extreme temperatures (*high confidence*). Vulnerable populations include the elderly, children, and those with existing chronic diseases.			Aging trends and prevailing social dynamics constrain effectiveness of adaptation responses.	25.8.1
	Significant reduction in food production in the Murray-Darling Basin, far south-eastern Australia, and some eastern and northern areas of New Zealand if scenarios of severe drying are realized (*high confidence*).			More efficient water use, allocation, and trading would increase the resilience of systems in the near term but cannot prevent significant reductions in agricultural production and severe consequences for ecosystems and some rural communities at the dry end of the projected range.	25.2, 25.5.1, 25.7.2, Box 25-5
North America	Without adaptation, projected changes in temperature, precipitation, and extreme events would result in notable productivity declines in major crops by the end of the 21st century (*very high confidence*). Given that North America is a significant source of global food supplies, there will *likely* be a negative effect on global food security if projected productivity declines are not addressed with substantial investments in adaptation (*medium confidence*).			Adaptation may ameliorate many climate impacts to agriculture, but current institutional support mechanisms are insufficient to ensure effective, equitable, and sustainable adaptation strategies.	26.5
Central and South America	Climate-change-related changes in agricultural productivity are expected to vary greatly spatially. In Southeastern South America, where projections indicate more rainfall, average productivity could be sustained or increased until the mid-century (SRES: A2, B2) (*medium confidence*). In Central America, northeast Brazil, and parts of the Andean region, increases in temperature and decreases in rainfall could decrease productivity in the short-term (before 2025), threatening food security of the poorest populations.				27.3.4
	It is *very likely* that climate variability and change may exacerbate current and future risks to health, given the region's vulnerabilities in existing health, water, sanitation and waste collection systems, nutrition, and pollution.				27.3.7
Polar Regions	Spatial convergence of impacts in different sectors creates impact "hotspots" involving new interactions, for example in the Arctic where sea ice loss and thawing disrupts transportation, buildings, other infrastructure, and potentially disrupts Inuit culture (*high confidence*).				19.3.2
	Significant impacts on the availability of key subsistence marine and terrestrial species are projected as climate continues to change with the ability to maintain economic livelihoods being affected (*high confidence*). Changing sea-ice conditions will result in more difficult access for hunting marine mammals.				28.2.6
Small Islands	Spatial convergence of impacts in different sectors creates impact "hotspots" involving new interactions, for example in the environs of Micronesia, Mariana Island, and Papua New Guinea where coral reefs are highly threatened due to exposure to concomitant sea surface temperature rise and ocean acidification (*high confidence*).	CO_2			19.3.2

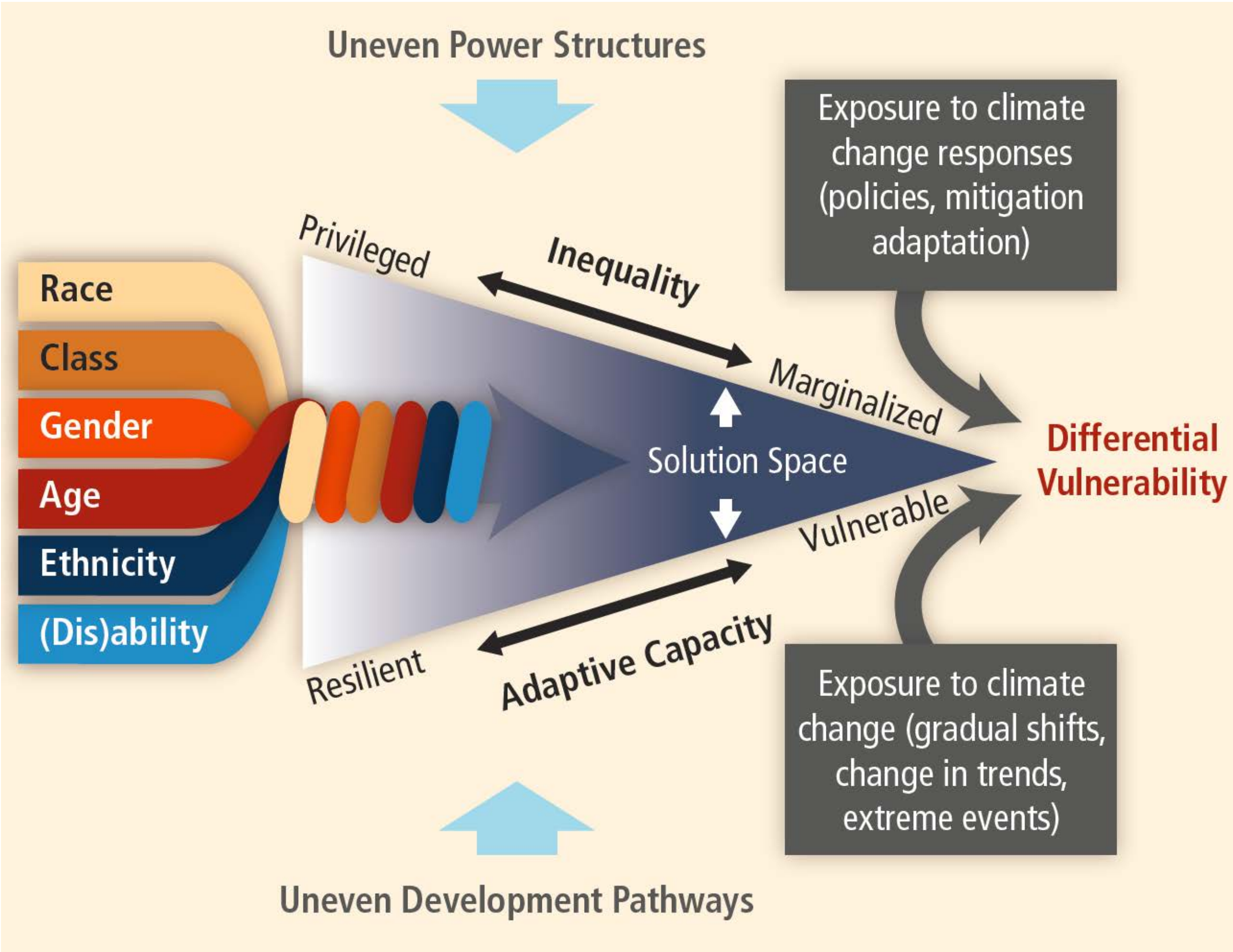
Table SPM.5: A selection of the hazards/stressors, key vulnerabilities, key risks, and emergent risks identified in the report. The examples underscore the complexity of risks determined by various climatic hazards, non-climatic stressors, and multifaceted vulnerabilities. The examples show that underlying phenomena, such as poverty or insecure land-tenure arrangements, demographic changes, or tolerance limits of species and ecosystems that often provide important services to vulnerable communities, generate the context in which climate-change-related harm and loss can occur. The examples illustrate that current global megatrends (e.g., climate change, urbanization, demographic changes), in combination and in specific development contexts (e.g., in low-lying coastal zones), can generate new systemic risks that go far beyond existing adaptation and risk management capacities, particularly in highly vulnerable regions. [Table 19-3]

Hazard/Stressor	Key vulnerabilities	Key risks	Emergent risks
Examples from terrestrial and inland water systems			
Rising air, soil, and water temperature.	Exceedence of eco-physiological climate tolerance limits of species, increased viability of alien organisms.	Loss of native biodiversity, increase in alien organism dominance.	Cascades of native species loss due to interdependencies.
	Epidemiological response to spread of temperature-sensitive vectors (insects).	Novel or much more severe pest and pathogen outbreaks.	Interactions between pest, drought, and fire interactions can lead to new risks and large negative impacts on ecosystems.
Examples from ocean systems			
Rising water temperature, increase of (thermal and haline) stratification, and marine acidification. [6.1.1] *(also Chapter 24)*	Tolerance limits of endemic species surpassed, increased abundance of invasive organisms, high vulnerability of warm water coral reefs and respective ecosystem services for coastal communities. [6.2.2, 6.2.5]	Loss of endemic species, mixing of ecosystem types, increased dominance of invasive organisms, loss of coral cover and associated ecosystems with reduction of biodiversity. [6.3.2]	Enhancement of risk due to interactions, e.g., acidification and warming for calcareous organisms. [6.3.5]
Examples from urban areas			
Inland flooding.	Urban areas with large numbers of poor, uninsured people exposed to flood events including low-income informal settlements. Environmental health consequences from overwhelmed, aging, poorly maintained, and inadequate urban drainage infrastructure combined with widespread impermeable surfaces. Inadequate local governance. Increased mosquito and water borne diseases.	Increasing urban flooding with increasing volume and velocity of flood waters on the one hand and increasing vulnerability on the other leads to key risks particularly in urban areas with large numbers of people who are poor and/or exposed to flooding.	Larger and more frequent flooding impacting a much larger population. Impacts reaching the limits of insurance; shift in the burden of risk management from the state to those at risk leading to greater inequality and property blight; abandonment of urban districts and the creation of high risk/high poverty spatial traps.
Changing hazard profile including novel hazards and new multi-hazard complexes.	Newly exposed populations and infrastructure, especially for those with limited capacity for multi-hazard risk forecasting and where risk reduction capacity is limited, e.g., where risk management planning is overly hazard specific including where physical infrastructure is predesigned in anticipation of other risks.	Risks from failures within coupled systems, e.g., reliance of drainage systems on electric pumps, reliance of emergency services on roads and telecommunications, psychological shock from unanticipated risks.	Loss of faith in risk management institutions. Potential for large events that are magnified by a lack of preparation and capacity to respond.
Examples from human health			
Increasing frequency and intensity of extreme heat. *(also chapter 19)*	Older people living in cities are most vulnerable to heat waves, and their population is projected to triple from 2010-2050.	Increased mortality and morbidity during heat waves, particularly in people with pre-existing conditions.	Overloading of health and emergency services. Mortality, morbidity, and productivity loss, particularly for manual workers in hot climates.
Increasing temperatures, increased variability in precipitation.	Food insecurity translates into malnutrition, which is among the largest disease burdens in poorer populations.	Progress in reducing mortality and morbidity from malnutrition may slow or reverse and constitutes a new key risk.	Combined impacts of climate impacts, population growth, plateauing productivity gains, land demand for livestock, biofuels, persistent inequity, and on-going food insecurity for the poor.
Examples from livelihoods and poverty			
Soaring demand (and prices) of biofuels due to climate change policies.	Unclear and/or insecure land tenure arrangements.	Risk of dispossession of land due to “land grabbing” in developing countries.	Creation of large groups of landless farmers unable to support themselves. Social unrest due to disparities between intensive energy production and neglected food production.
Increasing frequency of extreme events (droughts, floods). For example if 1:20 year drought/flood becomes 1:5 year flood/drought.	Livelihoods subject to damage to their productive assets (e.g. in case of droughts – herds of livestock; if floods – dikes, fences, terraces).	Risk of the loss of livelihoods and harm due to shorter time for recovery between extremes. Pastoralists restocking after a drought may take several years; in terraced agriculture, need to rebuild terraces after flood, which may take several years.	Collapse of coping strategies with risk of collapsing livelihoods. Adaptation mechanisms such as insurance fail due to increasing frequency of claims.

Hazard/Stressor	Key vulnerabilities	Key risks	Emergent risks
Examples from Chapter 19			
Warming and drying (degree of precipitation changes uncertain). [WGI AR5 SPM, TS.5.3, 11.3, 12.4]	Limits to coping capacity to deal with reduced water availability; increasing exposure and demand due to population increase; conflicting demands for alternative water uses; socio-cultural constraints on some adaptation options. [19.2.2, 19.3.2, 19.6.1, 19.7.5]	Risk of harm and loss due to livelihood degradation from systematic constraints on water resource use that lead to supply falling far below demand. In addition, limited coping and adaptation options increase the risk of harm and loss. [19.3.2]	Negative outcomes to sending and/or receiving regions from migration of populations due to limits on agricultural productivity and livelihoods. [19.3.2, 19.4.2]
Examples from Africa			
Increasing temperature.	Health of exposed and vulnerable groups (increased exposure to heat, change in the transmission dynamics of vector-borne diseases).	Increase in disease burden – changes in the patterns of infection. Decrease in outdoor worker productivity due to high temperature, increase in heat related morbidity and mortality.	Emerging and re-emerging disease epidemics.
	Vulnerability of aquatic systems and vulnerability of aquatic ecosystem services due to increased water temperatures.	Loss of aquatic ecosystems and risks for people who might depend on these resources.	
Examples from Europe			
Extreme weather events. *(also Chapter 19)*	Limited coping and adaptive capacity as well as high sensitivity of different sectors, e.g., transport, energy, and health.	Stress on multiple sectors can cause systemic risks due to interdependencies among sectors.	Disproportionate intensification of risk due to increasing interdependencies.
Examples from Asia			
Thawing of permafrost due to rising temperature in northern Asia.	Existence of structures and infrastructure on permafrost and high dependence of civil life on them.	Instability of or damage to structures and infrastructures.	Projected exacerbation of instability of residential buildings, pavements, pipelines used to transport petroleum and gas, pump stations, and extraction facilities.
Projected increase in frequency of various extreme events (heat waves, floods, and droughts) and sea level rise. *(also Chapter 19)*	Convergence of livelihoods and properties into coastal megacities, especially into areas not sufficiently protected against natural hazards.	Loss of human life and assets due to coastal floods accompanied by increasing vulnerabilities caused by occurrence of other extreme events like heat waves and droughts.	Projected increase in disruption of basic services such as water supply, sanitation, energy provision, and transportation systems, which themselves could increase vulnerabilities.
Examples from Australasia			
Warming and increased temperature high extremes in Australia. [25.2, Table 25-1, Figure 25-5]	Urbanization, aging of population and vital infrastructure. [25.3, Box 25-9, 25.10.2]	Increase in morbidity, mortality, and infrastructure failure during heat waves. [25.8.1, 25.10.2]	Increasing risk from compound extreme events across time, space and governance scales, and cumulative adaptation needs. [25.10.2, 25.10.3, Box 25-9]
Potential for sea level rise beyond 2100 exceeding 1m [25.2, WGI AR5 Chapter 13]	Long lifetime of coastal infrastructure, concentration and further expansion of coastal population and assets; conflicting priorities and time preferences constraining adaptation options; limited scope for managed retreat in highly developed areas.	Widespread damages to coastal infrastructure and low-lying ecosystems. [Box 25-1, 25.10.2]	
Examples from North America			
Increases in frequency and/or intensity of extreme events, such as hurricanes, river and coastal floods, heat waves, and droughts. [26.2] *(also Chapter 19)*	Declining state of physical infrastructure in urban areas as well as increases in income disparities. [26.7]	Risk of serious harm and losses in urban areas, particularly in coastal environments due to enhanced vulnerabilities of social groups and physical systems combined with increases of extreme weather events. [26.8]	Inability to reduce vulnerability in many areas results in increase in risk greater than change in physical hazard. [26.8]
Higher temperatures, decreases in runoff, and lower soil moisture. [26.2, 26.3]	Increasing vulnerability of small landholders in agriculture. [26.5]	Increased losses and decreases in agricultural production increase food and job insecurity for small landholders and social groups in that region. [26.5]	Increasing risks of social instability and local economic disruption due to internal migration. [26.2, 26.8]

Table SPM.6: Examples of potential tradeoffs among adaptation objectives. [Table 16-2]

Sector	Strategy	Adaptation Objective	Real or Perceived Externality
Agriculture	Biotechnology and genetically modified crops	Enhance drought and pest resistance; enhance yields	Perceived risk to public health and safety; ecological risks associated with introduction of new genetic variants to natural environments
	Subsidized drought assistance; crop insurance	Provide financial safety net for farmers to ensure continuation of farming enterprises	Creates moral hazard and inequality if not appropriately administered
	Increased use of chemical fertilizer and pesticides	Maintain or enhance crop yields; suppress opportunistic agricultural pests and invasive species	Increased discharge of nutrients and chemical pollution to the environment; increased emissions of greenhouse gases; increased human exposure to pollutants
Biodiversity	Migration corridors; expansion of conservation areas	Enable natural adaptation and migration to changing climatic conditions	Unknown efficacy; concerns over property rights regarding land acquisition; governance challenges
	Anticipatory endangerment listings	Enhance regulatory protections for species potentially at-risk due to climate change	Addresses secondary rather than primary pressures on species; concerns over property rights; regulatory barriers to economic development
	Assisted migration	Facilitate conservation of valued species	Potential for externalities for ecological and human systems due to species relocation
Coasts	Sea walls	Protect assets from inundation and/or erosion	High direct and opportunity costs; equity concerns; ecological impacts to coastal wetlands
	Managed retreat	Allow natural coastal and ecological processes; reduce long-term risk to property and assets	Undermines private property rights; significant governance challenges associated with implementation
	Migration out of low-lying areas	Preserve public health and safety; minimize property damage and risk of stranded assets	Loss of sense of place and cultural identity; erosion of kinship and familial ties; impacts to receiving communities
Water resources management	Desalination	Increase water resource reliability and drought resilience	Ecological risk of saline discharge; high energy demand and associated carbon emissions; creates disincentives for conservation
	Water trading	Maximize efficiency of water management and use; increases flexibility	Undermines public good/social aspects of water
	Water recycling/reuse	Enhance efficiency of available water resources	Perceived risk to public health and safety



Box SPM.3 Figure 1: Intersecting, simultaneous, and dynamic axes of privilege and marginalization, shaped by people's multiple identities and embedded in uneven power relations and development pathways. Together, they result in differential vulnerability to the same exposure to climate change and climate responses. [Figure 13-4]

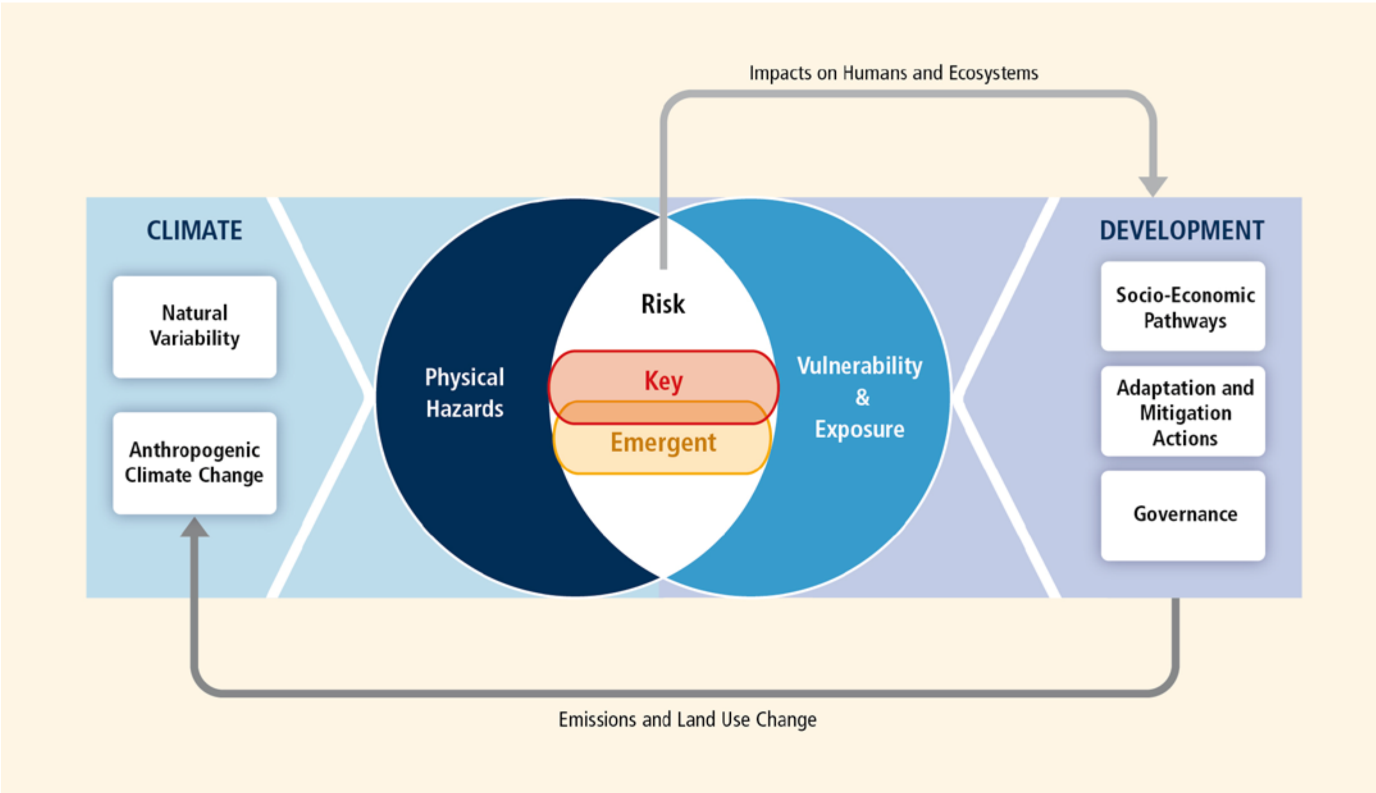


Figure SPM.1: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. Vulnerability and exposure are, as the figure shows, largely the result of socio-economic development pathways and societal conditions. Changes in both the climate system (left) and development processes (right) are key drivers of the different core components (vulnerability, exposure, and physical hazards) that constitute risk. The definition and use of “key” and “emergent” are indicated in Section C.ii. [19.1, Figure 19-1]

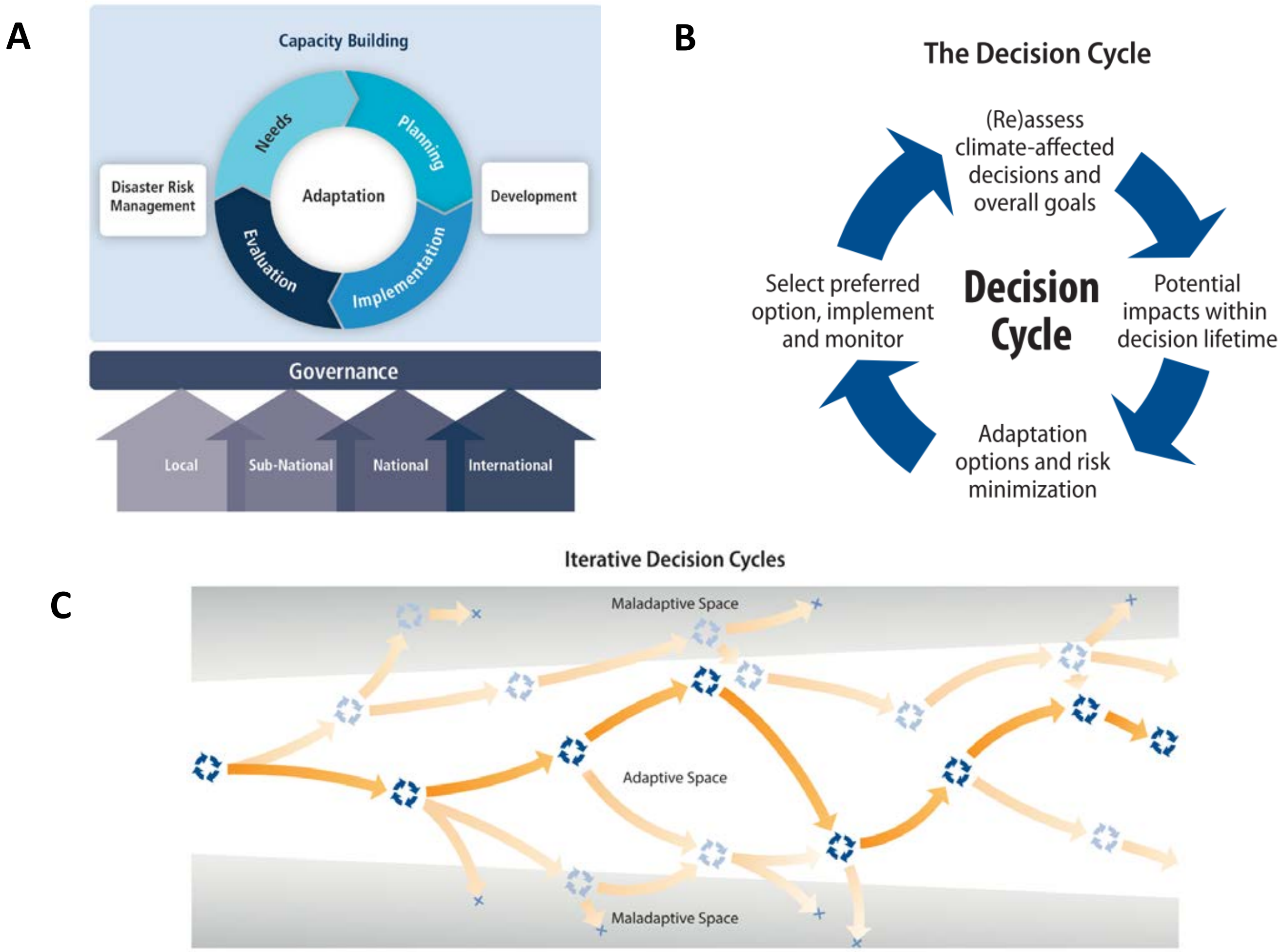
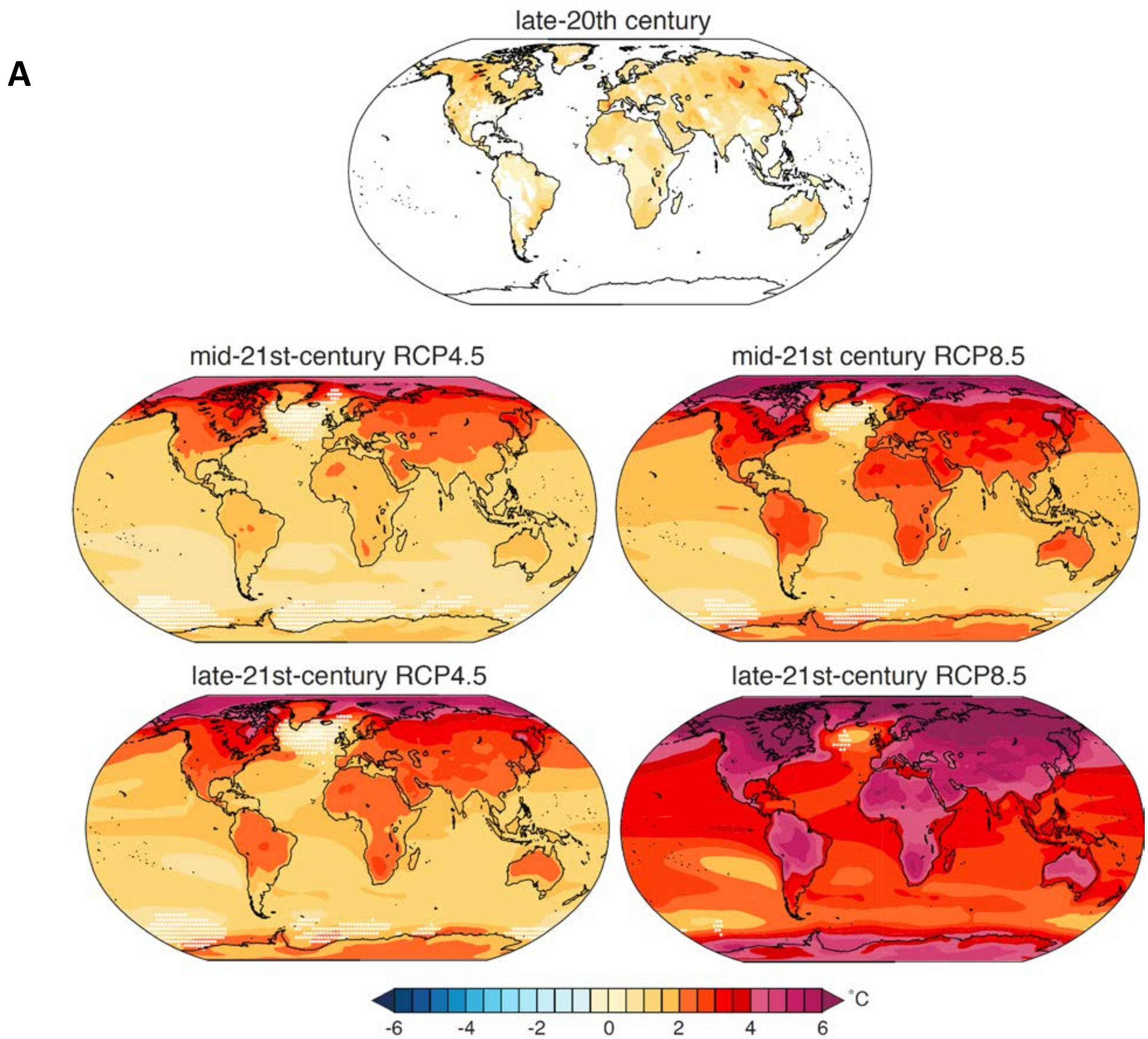
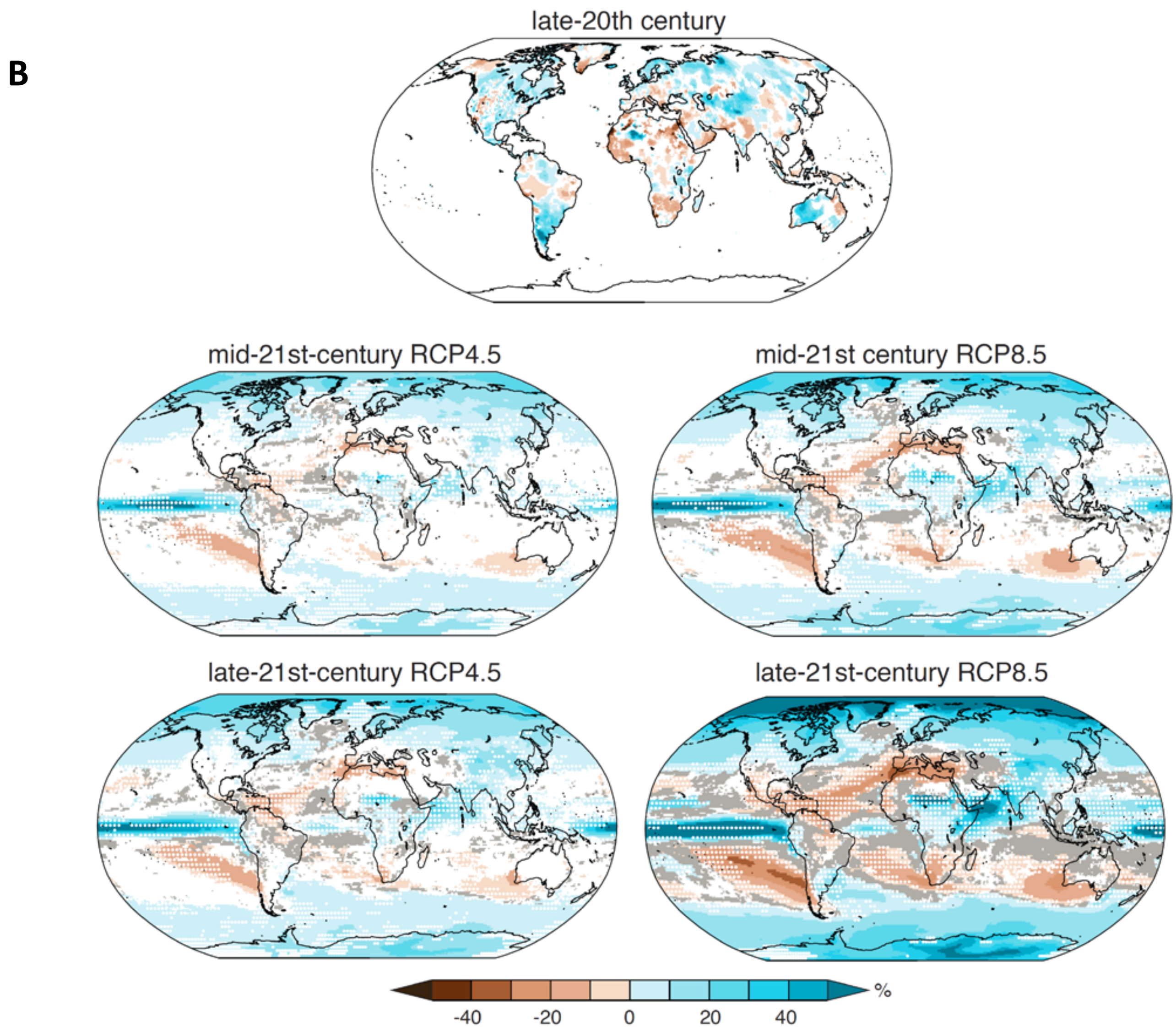


Figure SPM.2: Illustration of iterative response to climate change. (A) Four main phases of planned adaptation as a cyclic, iterative process: needs, planning, implementation, and evaluation. Efforts in adaptation can be linked with development or disaster risk management. Adaptation governance at multiple scales underlies capacity. (B) In the context of iterative risk management, each individual adaptation decision cycle comprises well known aspects of risk assessment and management. (C) A sequence of adaptation decisions creates an adaptation pathway. Some decisions, and sequences of decisions, are more likely to result in long-term maladaptive outcomes than others, but there is no single correct adaptation pathway and judgment of outcomes depends strongly on societal values, expectations, and goals. [Figures 15-1, 16-2, 25-6]



Box SUM.4 Figure 1: Changes in annual average temperature (A) and precipitation (B). For observations (top map, A and B; CRU), differences are shown over land between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For projections (bottom four maps, A and B; CMIP5), four classes of results are displayed. (1) White indicates areas where for >66% of models the annual average change is less than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Thus in these regions, more than 2/3 of models show no significant change in the annual average using this measure of significance, although this does not imply no significant change at seasonal or shorter time-scales such as months to days. (2) Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. In these regions, more than 2/3 of models show a significant change in annual average, but less than 2/3 agree on whether it will increase or decrease. (3) Colors with white circles indicate the change averaged over all models where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on whether the annual average will increase or decrease. In these regions, more than 2/3 of models show a significant change in annual average and more than 2/3 (but less than 90%) agree on whether it will increase or decrease. (4) Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on whether the annual average will increase or decrease. For models that have provided multiple realizations for the climate of the recent past and the future, results from each realization were first averaged to create the baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios were calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065. See also Annex I of WGI AR5. [Box CC-RC]



Box SUM.4 Figure 1: Changes in annual average temperature (A) and precipitation (B). For observations (top map, A and B; CRU), differences are shown over land between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For projections (bottom four maps, A and B; CMIP5), four classes of results are displayed. (1) White indicates areas where for >66% of models the annual average change is less than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Thus in these regions, more than 2/3 of models show no significant change in the annual average using this measure of significance, although this does not imply no significant change at seasonal or shorter time-scales such as months to days. (2) Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. In these regions, more than 2/3 of models show a significant change in annual average, but less than 2/3 agree on whether it will increase or decrease. (3) Colors with white circles indicate the change averaged over all models where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on whether the annual average will increase or decrease. In these regions, more than 2/3 of models show a significant change in annual average and more than 2/3 (but less than 90%) agree on whether it will increase or decrease. (4) Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on whether the annual average will increase or decrease. For models that have provided multiple realizations for the climate of the recent past and the future, results from each realization were first averaged to create the baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios were calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065. See also Annex I of WGI AR5. [Box CC-RC]

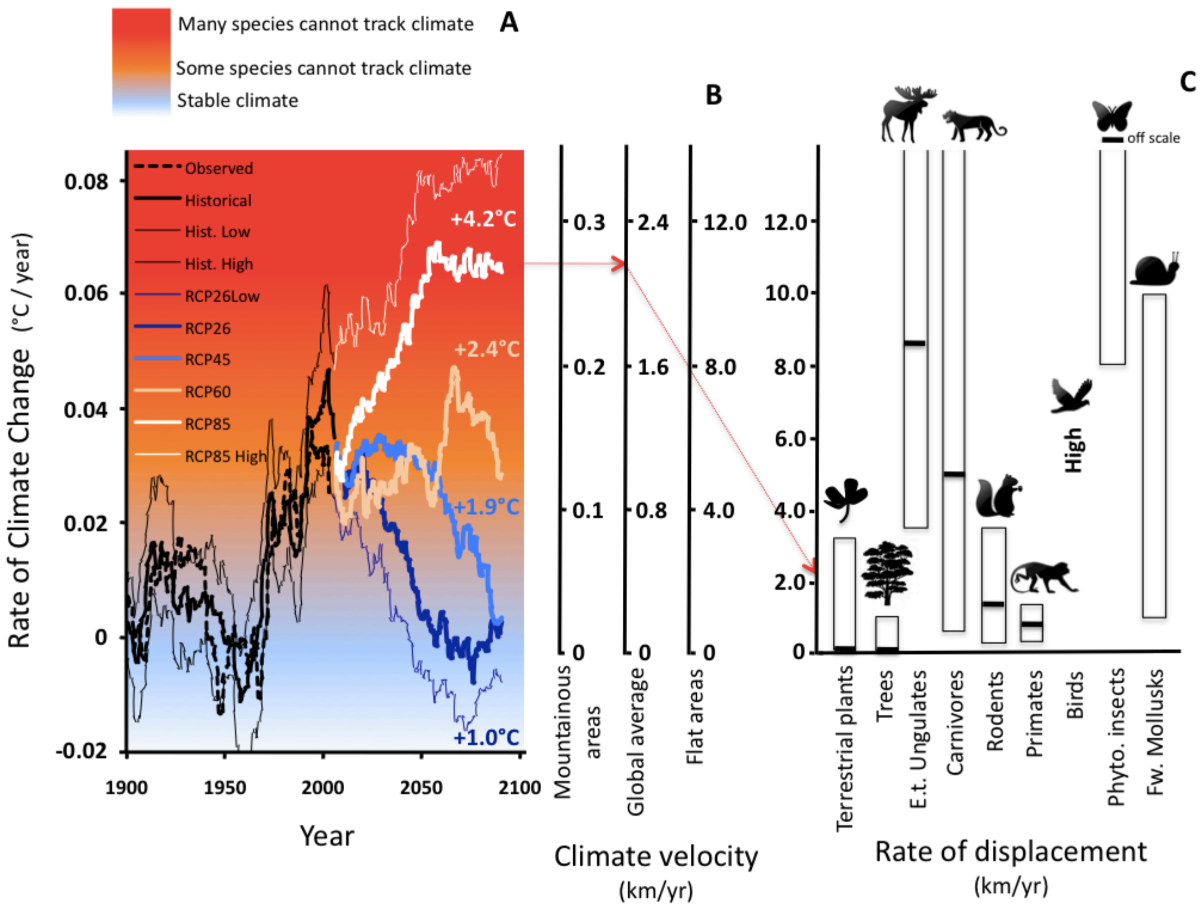


Figure SPM.3: Synthetic overview of projected abilities of some terrestrial and freshwater species to track climate by movement across landscapes. (A) Rates of climate change for global land areas. Black dotted line shows observed rates of climate change. Other rates were calculated from the CMIP5 ensemble for the historical period (black heavy line, with upper and lower bounds as light black lines) and for the future based on the four RCPs. A lower bound is given for RCP 2.6, and an upper bound for RCP 8.5. (B) Corresponding climate velocities, providing indication of the speed at which species' ranges would need to move to track changing climatic conditions. In mountainous areas with low climate velocities, species would only need to move short distances upslope to track a warming climate. In flat areas with high climate velocities, such as the Amazon basin, species would need to move large distances to track a warming climate. (C) Maximum estimated rates of displacement of several terrestrial and freshwater species groups, indicating how fast these groups can move across landscapes. Rates of species displacement are well defined for plants, especially trees, but less well defined for other groups. Displacement rates do not generally account for biotic interactions or human intervention that may speed or hinder dispersal. The thin red arrows give an example of interpretation: a rate of climate change of 0.065 °C/yr (approximately equal to projected rates by mid-century for RCP 8.5) corresponds to ~2.2 km/yr global average climate velocity. This global-average velocity would exceed projected maximum capacity for displacement for most plants, most primates, many rodents, and some less mobile species of other groups. For RCP 2.6, most species would be able to track climate by mid-century. Color gradient in panel A provides overall representation of the ability of species to track climate change. Detailed spatial analyses and maps of species displacement can be found in the references cited in WGII Chapter 4. E.t ungulates = even-toed ungulates; Phyto. insects = phytophagous (herbivorous) insects; Fw. mollusks = freshwater mollusks. [Figure 4-6]

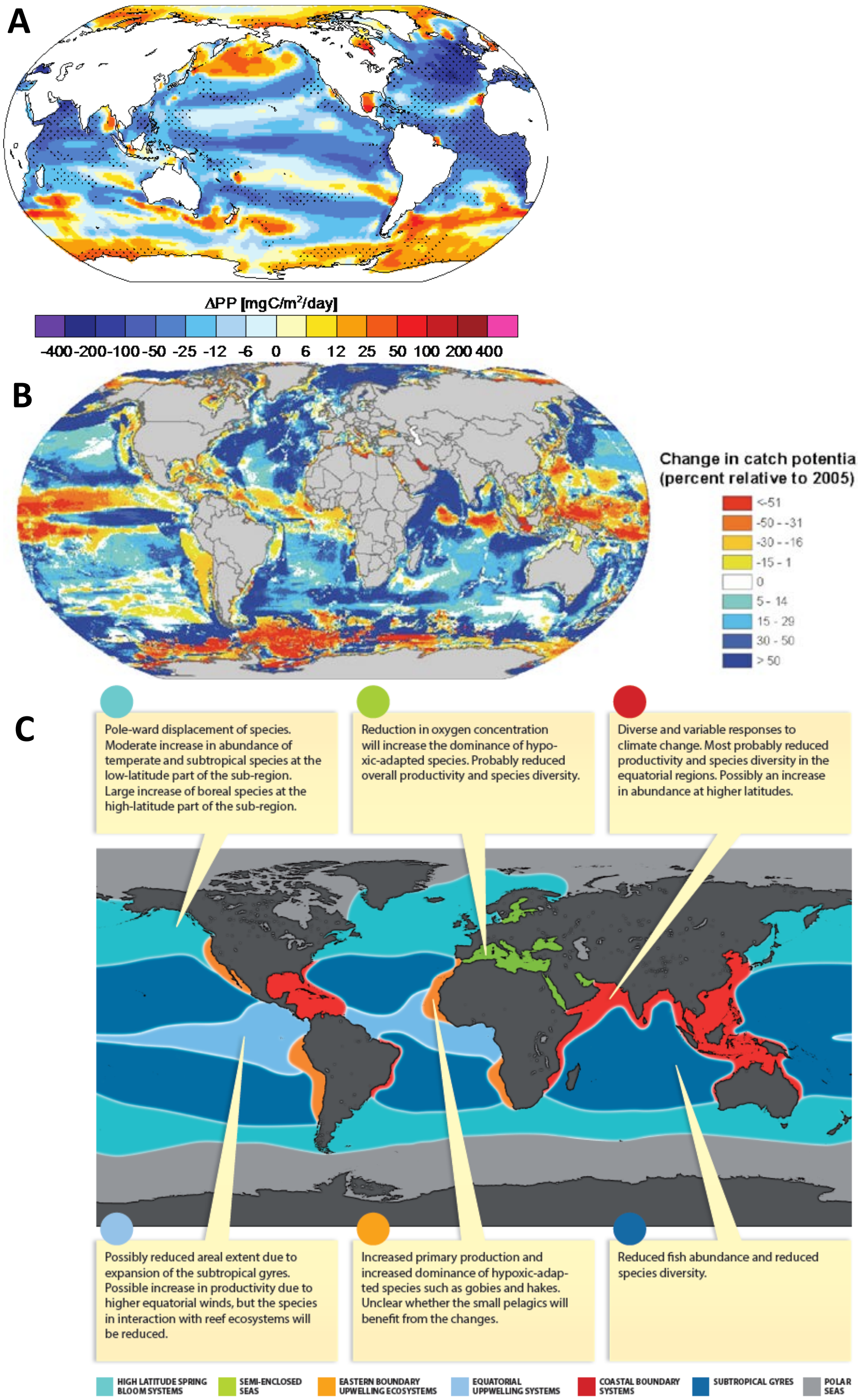


Figure SPM.4: (A) Multi-model mean changes of projected net primary production. To indicate consistency in the sign of change, regions are stippled where all models (four in total) agree on the sign of change. Changes are annual means under SRES A2 for the period 2080 to 2099 relative to 1870 to 1889. (B) A projection of maximum fisheries catch potential of 1000 species of exploited fishes and invertebrates from 2000 to 2050 under SRES A1B. (C) Example of changes occurring within fisheries across the ocean. [Figures 6-14, 6-15, and 30-15]

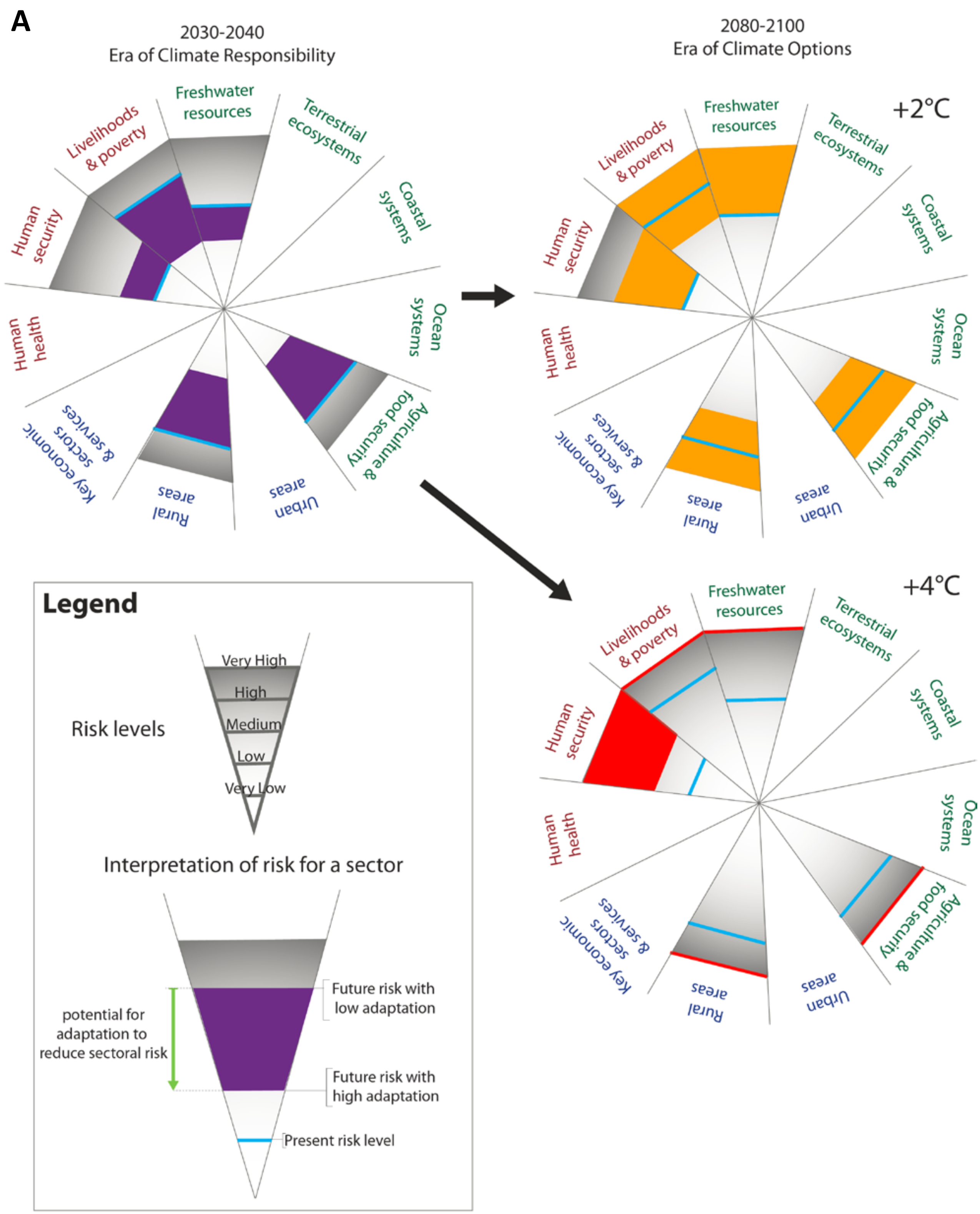


Figure SPM.5: Estimated risk from climate change to selected sectors and systems in Africa (A), Europe (B), and North America (C), for different time frames (2030-2040 and 2080-2100), under two levels of global average warming above preindustrial (2°C and 4°C) and different assumptions about adaptation to manage these risks. Levels of risk and of adaptation are differentiated by colored shading, ranging from high adaptation to low adaptation. Estimated risks rely on expert judgments. The risk categories reflect the overall structure of Part A of the WGII AR5. [Figures 22-7 and 26-6]

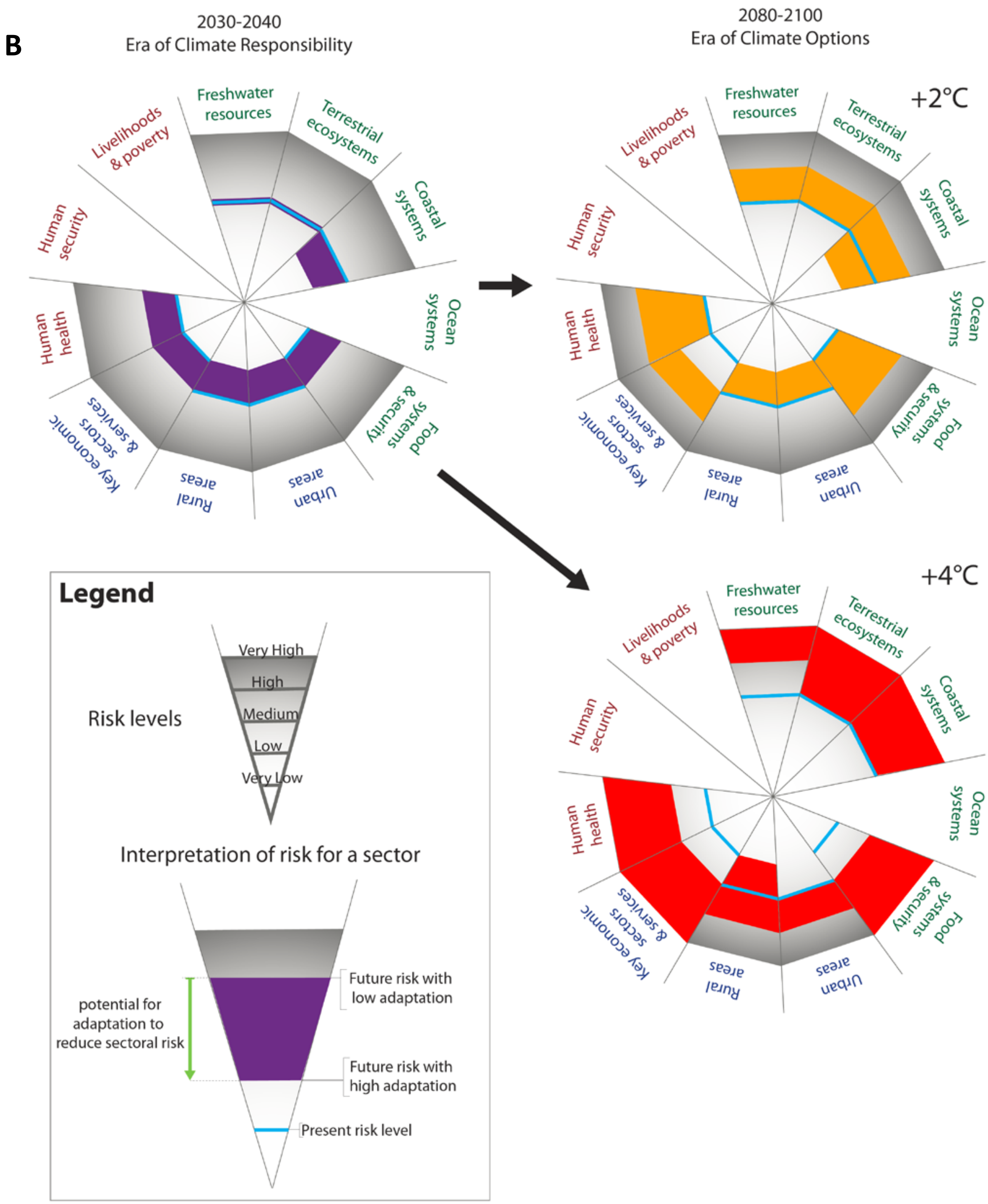


Figure SPM.5: Estimated risk from climate change to selected sectors and systems in Africa (A), Europe (B), and North America (C), for different time frames (2030-2040 and 2080-2100), under two levels of global average warming above preindustrial (2°C and 4°C) and different assumptions about adaptation to manage these risks. Levels of risk and of adaptation are differentiated by colored shading, ranging from high adaptation to low adaptation. Estimated risks rely on expert judgments. The risk categories reflect the overall structure of Part A of the WGII AR5. [Figures 22-7 and 26-6]

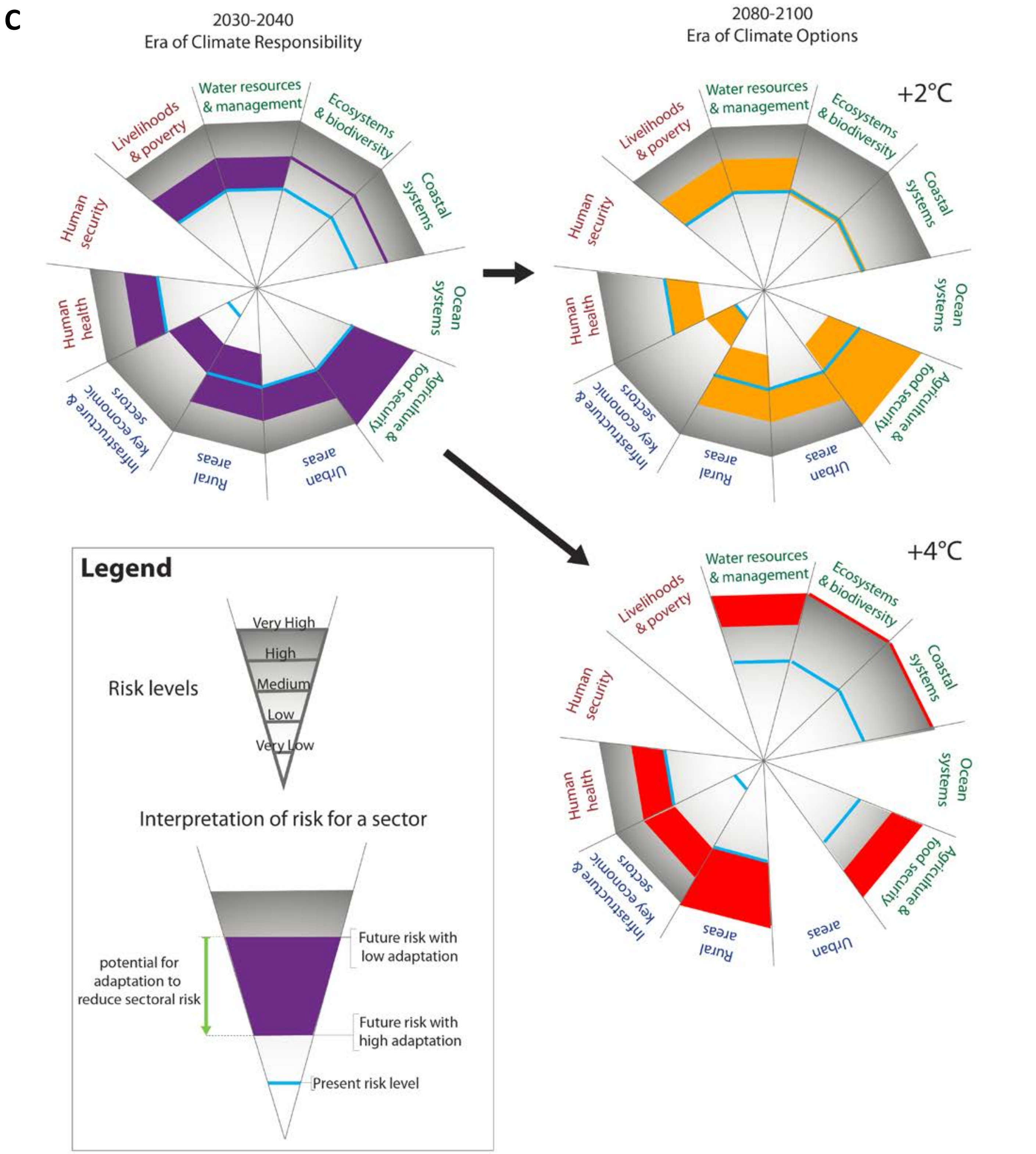


Figure SPM.5: Estimated risk from climate change to selected sectors and systems in Africa (A), Europe (B), and North America (C), for different time frames (2030-2040 and 2080-2100), under two levels of global average warming above preindustrial (2°C and 4°C) and different assumptions about adaptation to manage these risks. Levels of risk and of adaptation are differentiated by colored shading, ranging from high adaptation to low adaptation. Estimated risks rely on expert judgments. The risk categories reflect the overall structure of Part A of the WGII AR5. [Figures 22-7 and 26-6]

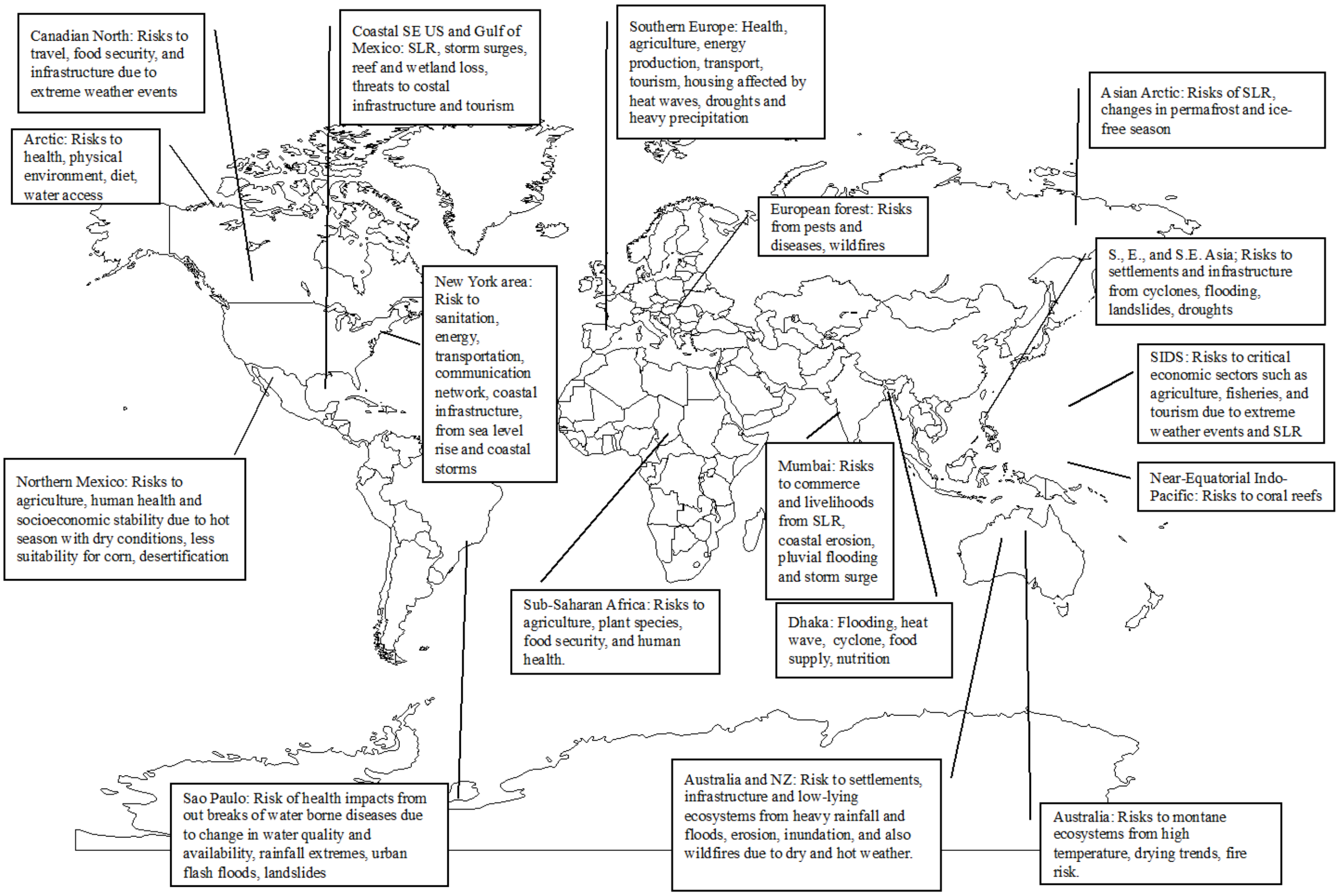
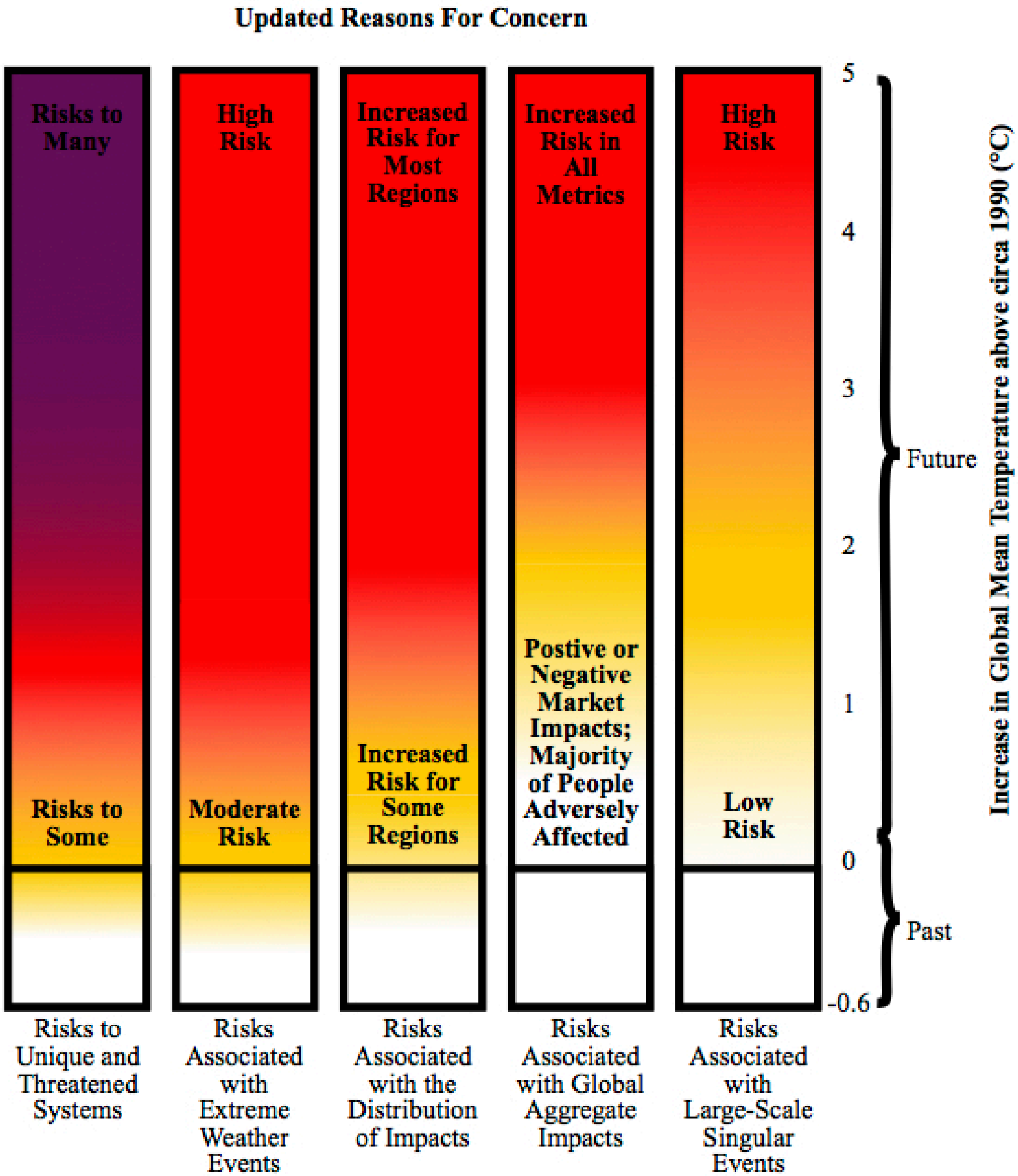
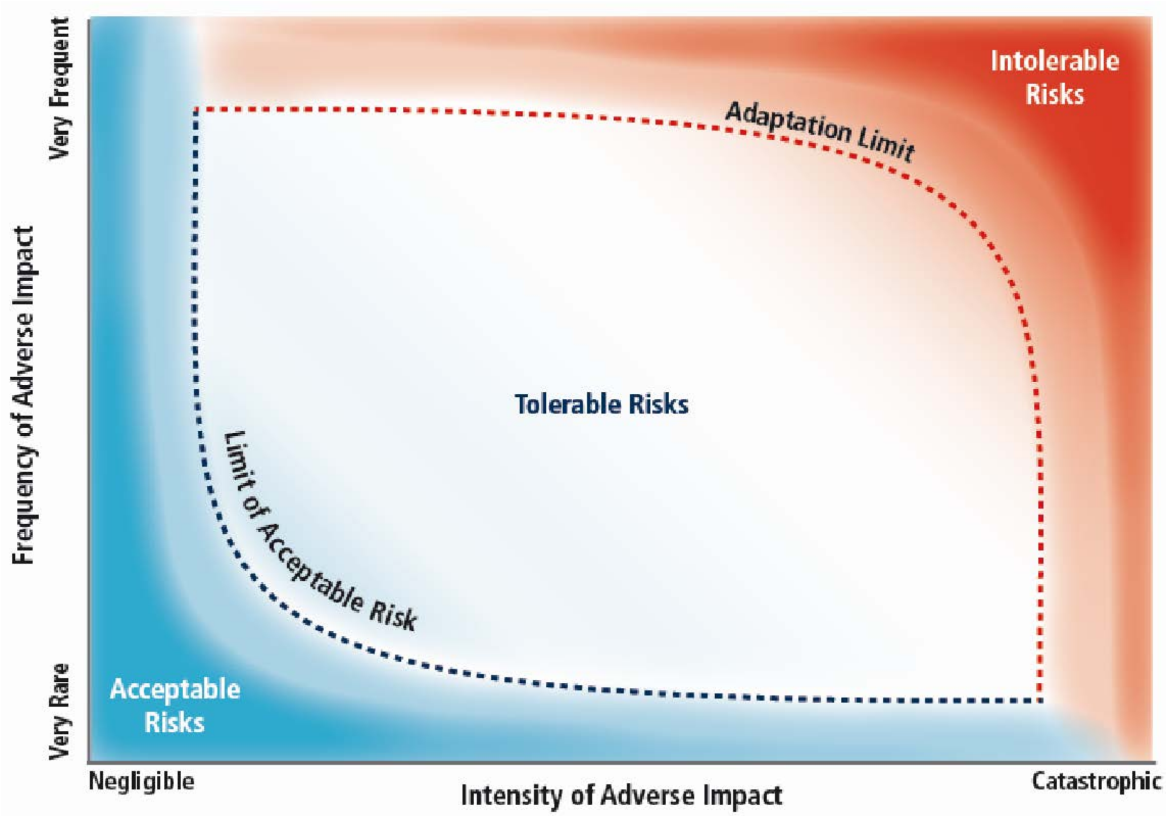


Figure SPM.6: Some salient examples of multi-impacts hotspots identified in this assessment. [Figure 19-2]



Box SPM.6 Figure 1: The dependence of risk associated with reasons for concern (RFCs) about climate change, updated based on expert judgment in this assessment. The color scheme indicates the additional risk due to climate change (with white to purple indicating the lowest to highest level of risk, respectively). Purple color, introduced here for the first time, reflects the assessment that unique human and natural systems tend to have very limited adaptive capacity. [Figure 19-5]



Box SPM.7 Figure 1: Conceptual model of acceptable, tolerable, and intolerable risks and implications for limits to adaptation. [16.2, Figure 16-1]