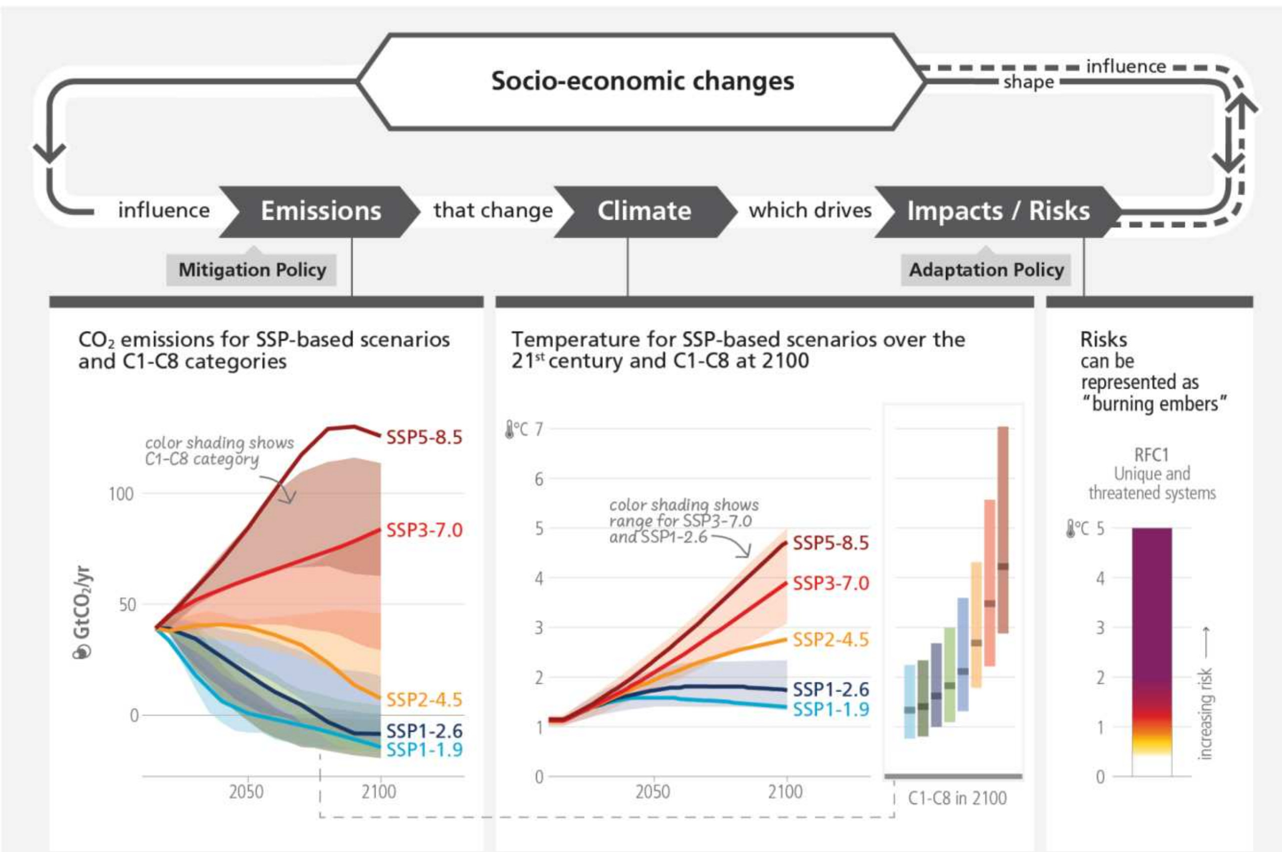
Risks

Dynamic interactions between climate-related hazards, exposure and vulnerability of the affected human society, species, or ecosystems result in risks arising from climate change. AR6 assesses key risks across sectors and regions as well as providing an updated assessment of the Reasons for Concern (RFCs) – five globally aggregated categories of risk that evaluate risk accrual with increasing global surface temperature. Risks can also arise from climate change mitigation or adaptation responses when the response does not achieve its intended objective, or when it results in adverse effects for other societal objectives. {WGII SPM A, WGII Figure SPM.3, WGII Box TS.1, WGII Figure TS.4; SR1.5 Figure SPM.2; SRCCL Figure SPM.2; SROCC Errata Figure SPM.3} (3.1.2, Cross-Section Box.2, Figure 1; Figure 3.3)

[START CROSS-SECTION BOX.2, FIGURE 1 HERE]

Scenarios and warming levels structure our understanding across the cause-effect chain from emissions to climate change and risks

a) **AR6 integrated assessment framework on future climate, impacts and mitigation**



b) **Scenarios and pathways across AR6 Working Group reports**

Category in WGIII	Category description	GHG emissions scenarios (SSPx-y*) in WGI & WGII	RCPy** in WGI & WGII
C1	limit warming to 1.5°C (>50%) with no or limited overshoot	Very low (SSP1-1.9)	
C2	return warming to 1.5°C (>50%) after a high overshoot		
C3	limit warming to 2°C (>67%)	Low (SSP1-2.6)	RCP2.6
C4	limit warming to 2°C (>50%)		
C5	limit warming to 2.5°C (>50%)		
C6	limit warming to 3°C (>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	exceed warming of 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

c) **Determinants of risk**

* The terminology SSPx-y is used, where 'SSPx' refers to the Shared Socio-economic Pathway or 'SSP' describing the socio-economic trends underlying the scenario, and 'y' refers to the approximate level of radiative forcing (in watts per square metre, or W m^{-2}) resulting from the scenario in the year 2100.

** The AR5 scenarios (RCPy), which partly inform the AR6 WGI and WGII assessments, are indexed to a similar set of approximate 2100 radiative forcing levels (in Wm^{-2}). The SSP scenarios cover a broader range of GHG and air pollutant futures than the RCPs. They are similar but not identical, with differences in concentration trajectories for different GHGs. The overall radiative forcing tends to be higher for the SSPs compared to the RCPs with the same label (*medium confidence*). {WGI TS.1.3.1}
*** Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C, high overshoot by 0.1°C-0.3°C, in both cases for up to several decades.

Cross-Section Box.2, Figure 1: Schematic of the AR6 framework for assessing future greenhouse gas emissions, climate change, risks, impacts and mitigation. Panel (**a**) The integrated framework encompasses socio-economic development and policy, emissions pathways and global surface temperature responses to the five scenarios considered by WGI (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) and eight global mean temperature change categorisations (C1–C8) assessed by WGIII, and the WGII risk assessment. The dashed arrow indicates that the influence from impacts/risks to socio-economic changes is not yet considered in the scenarios assessed in the AR6. Emissions include GHGs, aerosols, and ozone precursors. CO_2 emissions are shown as an example on the left. The assessed global surface temperature changes across the 21st century relative to 1850–1900 for the five GHG emissions scenarios are shown as an example in the centre. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0. Projected temperature outcomes at 2100 relative to 1850–1900 are shown for C1 to C8 categories with median (line) and the combined *very likely* range across scenarios (bar). On the right, future risks due to increasing warming are represented by an example 'burning ember' figure (see 3.1.2 for the definition of RFC1). **Panel** (**b**) Description and relationship of scenarios considered across AR6 Working Group reports. **Panel** (**c**) Illustration of risk arising from the interaction of hazard (driven by changes in climatic impact-drivers) with vulnerability, exposure and response to climate change. {WGI TS1.4, Figure 4.11; WGII Figure 1.5, WGII Figure 14.8; WGIII Table SPM.2, Figure 3.11}

[END CROSS-SECTION BOX.2 FIGURE 1 HERE]

[END CROSS-SECTION BOX.2 HERE]

Section 3: Long-Term Climate and Development Futures

3.1 Long-Term Climate Change, Impacts and Related Risks

Future warming will be driven by future emissions and will affect all major climate system components, with every region experiencing multiple and co-occurring changes. Many climate-related risks are assessed to be higher than in previous assessments, and projected long-term impacts are up to multiple times higher than currently observed. Multiple climatic and non-climatic risks will interact, resulting in compounding and cascading risks across sectors and regions. Sea level rise, as well as other irreversible changes, will continue for thousands of years, at rates depending on future emissions. (*high confidence*)

3.1.1 Long-term Climate Change

The uncertainty range on assessed future changes in global surface temperature is narrower than in the AR5. For the first time in an IPCC assessment cycle, multi-model projections of global surface temperature, ocean warming and sea level are constrained using observations and the assessed climate sensitivity. The *likely* range of equilibrium climate sensitivity has been narrowed to 2.5°C–4.0°C (with a best estimate of 3.0°C) based on multiple lines of evidence[55], including improved understanding of cloud feedbacks. For related emissions scenarios, this leads to narrower uncertainty ranges for long-term projected global temperature change than in AR5. {WGI A.4, WGI Box SPM.1, WGI TS.3.2, WGI 4.3}

Future warming depends on future greenhouse gas (GHG) emissions, with cumulative net CO_2 dominating. The assessed best estimates and *very likely* ranges of warming for 2081–2100 with respect to 1850–1900 vary from 1.4°C [1.0-1.8°C] in the very low GHG emissions scenario (SSP1-1.9) to 2.7°C [2.1°C–3.5°C] in the intermediate GHG emissions scenario (SSP2-4.5) and 4.4°C [3.3°C–5.7°C] in the very high GHG emissions scenario (SSP5-8.5)[56]. {WGI SPM B.1.1, WGI Table SPM.1, WGI Figure SPM.4} (Cross-Section Box.2, Figure 1)

Modelled pathways consistent with the continuation of policies implemented by the end of 2020 lead to global warming of 3.2 [2.2-3.5]°C (5–95% range) by 2100 (*medium confidence*) (see also Section 2.3.1). Pathways of >4°C (≥50%) by 2100 would imply a reversal of current technology and/or mitigation policy trends (*medium confidence*). However, such warming could occur in emissions pathways consistent with policies implemented by the end of 2020 if climate sensitivity or carbon cycle feedbacks are higher than the best estimate (*high confidence*). {WGIII SPM C.1.3}

Global warming will continue to increase in the near term in nearly all considered scenarios and modelled pathways. Deep, rapid and sustained GHG emissions reductions, reaching net zero CO_2 emissions and including strong emissions reductions of other GHGs, in particular CH_4, are necessary to limit warming to 1.5°C (>50%) or less than 2°C (>67%) by the end of century (*high confidence*). The best estimate of reaching 1.5°C of global warming lies in the first half of the 2030s in most of the considered scenarios and modelled pathways[57]. In the very low GHG emissions scenario (SSP1-1.9), CO_2 emissions reach net zero around 2050 and the best-estimate end-of-century warming is 1.4°C, after a temporary overshoot (see Section 3.3.4) of no more than 0.1°C above 1.5°C global warming. Global warming of 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other GHG emissions occur in the coming decades.

[55] Understanding of climate processes, the instrumental record, paleoclimates and model-based emergent constraints (see Annex I: Glossary). {WGI SPM footnote 21}

[56] The best estimates [and *very likely* ranges] for the different scenarios are: 1.4°C [1.0°C–1.8°C] (SSP1-1.9); 1.8°C [1.3°C–2.4°C] (SSP1-2.6); 2.7°C [2.1°C–3.5°C] (SSP2-4.5); 3.6°C [2.8°C–4.6°C] (SSP3-7.0); and 4.4°C [3.3°C–5.7°C] (SSP5-8.5). {WGI Table SPM.1} (CSB.2)

[57] In the near term (2021–2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high GHG emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high GHG emissions scenarios (SSP2-4.5, SSP3-7.0), *more likely than not* to be exceeded under the low GHG emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low GHG emissions scenario (SSP1-1.9). In all scenarios considered by WGI except the very high emissions scenario, the midpoint of the first 20-year running average period during which the assessed global warming reaches 1.5°C lies in the first half of the 2030s. In the very high GHG emissions scenario, this mid-point is in the late 2020s. Median five-year interval at which a 1.5°C global warming level is reached (50% probability) in categories of modelled pathways considered in WGIII is 2030-2035. {WGI SPM B.1.3, WGI Cross-Section Box TS.1, WGIII Table 3.2} (Cross-Section Box.2)

Deep, rapid and sustained reductions in GHG emissions would lead to improvements in air quality within a few years, to reductions in trends of global surface temperature discernible after around 20 years, and over longer time periods for many other climate impact-drivers[58] (*high confidence*). Targeted reductions of air pollutant emissions lead to more rapid improvements in air quality compared to reductions in GHG emissions only, but in the long term, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions (*high confidence*)[59]. {WGI SPM B.1, WGI SPM B.1.3, WGI SPM D.1, WGI SPM D.2, WGI Figure SPM.4, WGI Table SPM.1, WGI Cross-Section Box TS.1; WGIII SPM C.3, WGIII Table SPM.2, WGIII Figure SPM.5, WGIII Box SPM.1 Figure 1, WGIII Table 3.2} (Table 3.1, Cross-Section Box 2, Figure 1)

Changes in short-lived climate forcers (SLCF) resulting from the five considered scenarios lead to an additional net global warming in the near and long term (*high confidence*). Simultaneous stringent climate change mitigation and air pollution control policies limit this additional warming and lead to strong benefits for air quality (*high confidence*). In high and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.5), combined changes in SLCF emissions, such as CH_4, aerosol and ozone precursors, lead to a net global warming by 2100 of *likely* 0.4°C–0.9°C relative to 2019. This is due to projected increases in atmospheric concentration of CH_4, tropospheric ozone, hydrofluorocarbons and, when strong air pollution control is considered, reductions of cooling aerosols. In low and very low GHG emissions scenarios (SSP1-1.9 and SSP1-2.6), air pollution control policies, reductions in CH_4 and other ozone precursors lead to a net cooling, whereas reductions in anthropogenic cooling aerosols lead to a net warming (*high confidence*). Altogether, this causes a *likely* net warming of 0.0°C–0.3°C due to SLCF changes in 2100 relative to 2019 and strong reductions in global surface ozone and particulate matter (*high confidence*). {WGI SPM D.1.7, WGI Box TS.7} (CSB.2)

Continued GHG emissions will further affect all major climate system components, and many changes will be irreversible on centennial to millennial time scales. Many changes in the climate system become larger in direct relation to increasing global warming. With every additional increment of global warming, changes in extremes continue to become larger. Additional warming will lead to more frequent and intense marine heatwaves and is projected to further amplify permafrost thawing and loss of seasonal snow cover, glaciers, land ice and Arctic sea ice (*high confidence*). Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation[60], and very wet and very dry weather and climate events and seasons (*high confidence*). The portion of global land experiencing detectable changes in seasonal mean precipitation is projected to increase (*medium confidence*) with more variable precipitation and surface water flows over most land regions within seasons (*high confidence*) and from year to year (*medium confidence*). Many changes due to past and future GHG emissions are irreversible[61] on centennial to millennial time scales, especially in the ocean, ice sheets and global sea level (see 3.1.3). Ocean acidification (*virtually certain*), ocean deoxygenation (*high confidence*) and global mean sea level (*virtually certain*) will continue to increase in the 21st century, at rates dependent on future emissions. {WGI SPM B.2, WGI SPM B.2.2, WGI SPM B.2.3, WGI SPM B.2.5, WGI SPM B.3, WGI SPM B.3.1, WGI SPM B.3.2, WGI SPM B.4, WGI SPM B.5, WGI SPM B.5.1, WGI SPM B.5.3, WGI Figure SPM.8} (Figure 3.1)

With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Increases in hot and decreases in cold climatic impact-drivers, such as temperature extremes, are projected in all regions (*high confidence*). At 1.5°C global warming, heavy precipitation and flooding events are projected to intensify and become more frequent in most regions in Africa, Asia (*high confidence*), North America (*medium to high confidence*) and Europe (*medium confidence*). At 2°C or above, these changes expand to more regions and/or become more significant (*high confidence*), and more frequent and/or severe agricultural and ecological droughts are projected in Europe, Africa, Australasia and North, Central and South America (*medium* to *high confidence*). Other projected regional changes include intensification of tropical cyclones and/or extratropical storms (*medium confidence*), and increases in aridity and fire weather[62] (*medium* to *high confidence*). Compound heatwaves and droughts

[58] See Cross-Section Box.2.
[59] Based on additional scenarios.
[60] Particularly over South and South East Asia, East Asia and West Africa apart from the far west Sahel {WGI SPM B.3.3}
[61] See Annex I: Glossary.
[62] See Annex I: Glossary.

become *likely* more frequent, including concurrently at multiple locations (*high confidence*). {WGI SPM C.2, WGI SPM C.2.1, WGI SPM C.2.2, WGI SPM C.2.3, WGI SPM C.2.4, WGI SPM C.2.7}

[START FIGURE 3.1 HERE]

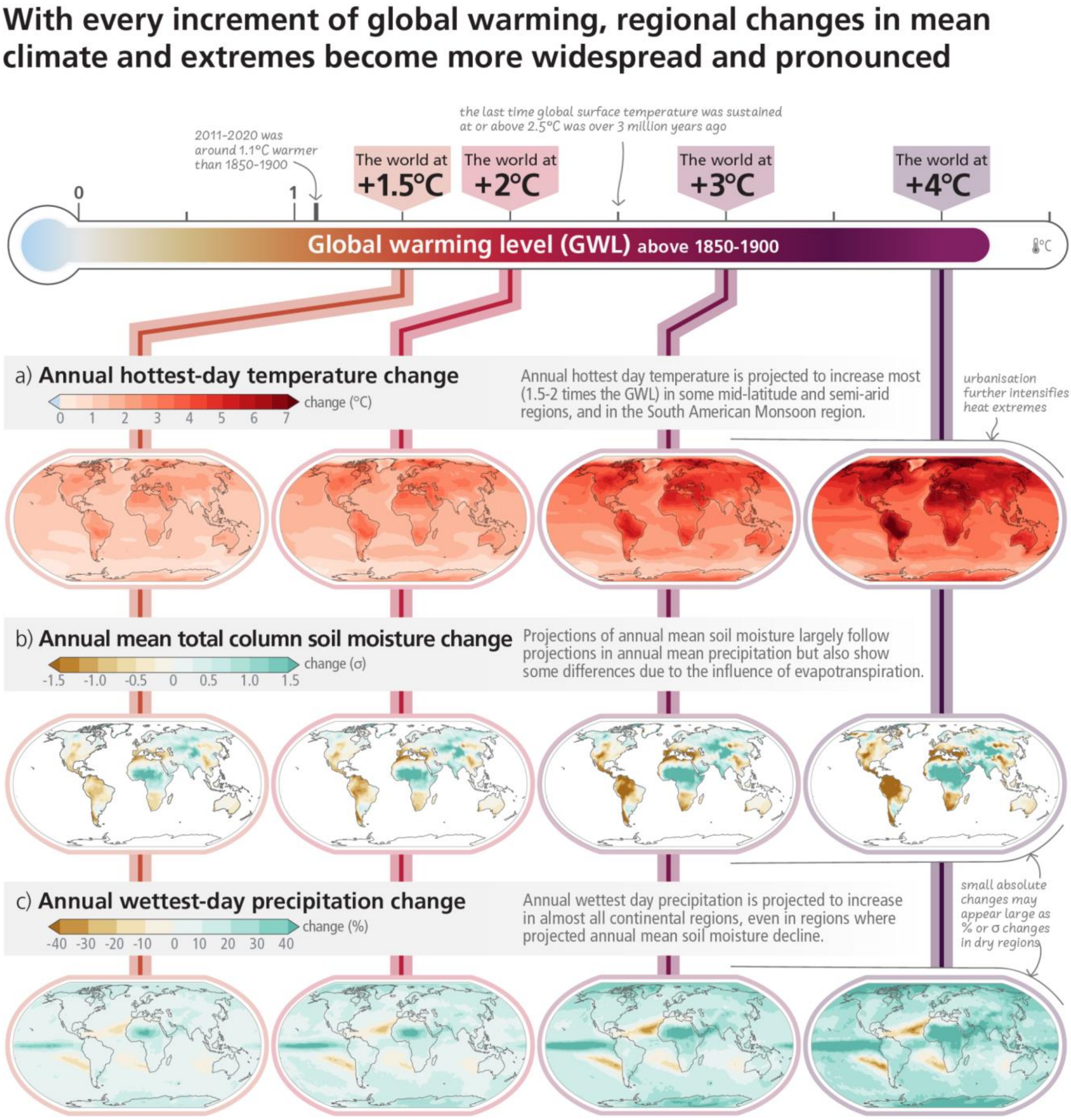


Figure 3.1: Projected changes of annual maximum daily temperature, annual mean total column soil moisture CMIPand annual maximum daily precipitation at global warming levels of 1.5°C, 2°C, 3°C, and 4°C relative to 1850–1900. Simulated (**a**) annual maximum temperature change (°C), (**b**) annual mean total column soil moisture (standard deviation), (**c**) annual maximum daily precipitation change (%). Changes correspond to CMIP6 multi-model median changes. In panels (b) and (c), large positive relative changes in dry regions may correspond to small absolute changes. In panel (b), the unit is the standard deviation of interannual variability in soil moisture during 1850–1900. Standard deviation is a widely used metric in characterising drought severity. A projected reduction in mean soil moisture by one standard deviation corresponds to soil moisture conditions typical of droughts that occurred about once every six years during 1850–1900. The WGI Interactive Atlas (https://interactive-atlas.ipcc.ch/) can be used to explore additional changes in the climate system across the range of global warming levels presented in this figure. {WGI Figure SPM.5, WGI Figure TS.5, WGI Figure 11.11, WGI Figure 11.16, WGI Figure 11.19} (CSB.2)

[END FIGURE 3.1 HERE]

3.1.2 Impacts and Related Risks

For a given level of warming, many climate-related risks are assessed to be higher than in AR5 (*high confidence*). Levels of risk[63] for all Reasons for Concern[64] (RFCs) are assessed to become high to very high at lower global warming levels compared to what was assessed in AR5 (*high confidence*). This is based upon recent evidence of observed impacts, improved process understanding, and new knowledge on exposure and vulnerability of human and natural systems, including limits to adaptation. Depending on the level of global warming, the assessed long-term impacts will be up to multiple times higher than currently observed (*high confidence*) for 127 identified key risks, e.g., in terms of the number of affected people and species. Risks, including cascading risks (see 3.1.3) and risks from overshoot (see 3.3.4), are projected to become increasingly severe with every increment of global warming (*very high confidence*). {WGII SPM B.3.3, WGII SPM B.4, WGII SPM B.5, WGII 16.6.3; SRCCL SPM A5.3} (Figure 3.2, Figure 3.3)

Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present (1.1°C) but lower than at 2°C (*high confidence*) (see Section 2.1.2)**.** Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C. In terrestrial ecosystems, 3–14% of the tens of thousands of species assessed will *likely* face a very high risk of extinction at a GWL of 1.5°C. Coral reefs are projected to decline by a further 70–90% at 1.5°C of global warming (*high confidence*). At this GWL, many low-elevation and small glaciers around the world would lose most of their mass or disappear within decades to centuries (*high confidence*). Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, small island development states and Least Developed Countries (*high confidence*). {WGII SPM B.3, WGII SPM B.4.1, WGII TS.C.4.2; SR1.5 SPM A.3, SR1.5 SPM B.4.2, SR1.5 SPM B.5, SR1.5 SPM B.5.1} (Figure 3.3)

At 2°C of global warming, overall risk levels associated with the unequal distribution of impacts (RFC3), global aggregate impacts (RFC4) and large-scale singular events (RFC5) would be transitioning to high (*medium confidence*), those associated with extreme weather events (RFC2) would be transitioning to very high (*medium confidence*), and those associated with unique and threatened systems (RFC1) would be very high (*high confidence*) (Figure 3.3, panel a). With about 2°C warming, climate-related changes in food availability and diet quality are estimated to increase nutrition-related diseases and the number of undernourished people, affecting tens (under low vulnerability and low warming) to hundreds of millions of people (under high vulnerability and high warming), particularly among low-income households in low- and middle-income countries in sub-Saharan Africa, South Asia and Central America (*high confidence*). For example, snowmelt water availability for irrigation is projected to decline in some snowmelt dependent river basins by up to 20% (*medium confidence*). Climate change risks to cities, settlements and key infrastructure will rise sharply in the mid- and long-term with further global warming, especially in places already exposed to high temperatures, along coastlines, or with high vulnerabilities (*high confidence*). {WGII SPM B.3.3, WGII SPM B.4.2, WGII SPM B.4.5, WGII TS C.3.3, WGII TS.C.12.2} (Figure 3.3)

---

[63] Undetectable risk level indicates no associated impacts are detectable and attributable to climate change; moderate risk indicates associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks; high risk indicates severe and widespread impacts that are judged to be high on one or more criteria for assessing key risks; and very high risk level indicates very high risk of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks. {WGII Figure SPM.3}

[64] The Reasons for Concern (RFC) framework communicates scientific understanding about accrual of risk for five broad categories {WGII Figure SPM.3}. RFC1: Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its Indigenous Peoples, mountain glaciers and biodiversity hotspots. RFC2: Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heatwaves, heavy rain, drought and associated wildfires, and coastal flooding. RFC3: Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability. RFC4: Global aggregate impacts: impacts to socio-ecological systems that can be aggregated globally into a single metric, such as monetary damages, lives affected, species lost or ecosystem degradation at a global scale. RFC5: Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming, such as ice sheet instability or thermohaline circulation slowing. Assessment methods include a structured expert elicitation based on the literature described in WGII SM16.6 and are identical to AR5 but are enhanced by a structured approach to improve robustness and facilitate comparison between AR5 and AR6. For further explanations of global risk levels and Reasons for Concern, see WGII TS.AII. {WGII Figure SPM.3}

At global warming of 3°C, additional risks in many sectors and regions reach high or very high levels, implying widespread systemic impacts, irreversible change and many additional adaptation limits (see Section 3.2) (*high confidence*). For example, very high extinction risk for endemic species in biodiversity hotspots is projected to increase at least tenfold if warming rises from 1.5°C to 3°C (*medium confidence*). Projected increases in direct flood damages are higher by 1.4–2 times at 2°C and 2.5–3.9 times at 3°C, compared to 1.5°C global warming without adaptation (*medium confidence*). {WGII SPM B.4.1, WGII SPM B.4.2, WGII Figure SPM.3, WGII TS Appendix AII, WGII Atlas Fig.AI.46} (Figure 3.2, Figure 3.3)

Global warming of 4°C and above is projected to lead to far-reaching impacts on natural and human systems (*high confidence*). Beyond 4°C of warming, projected impacts on natural systems include local extinction of ~50% of tropical marine species (*medium confidence*) and biome shifts across 35% of global land area (*medium confidence*). At this level of warming, approximately 10% of the global land area is projected to face both increasing high and decreasing low extreme streamflow, affecting, without additional adaptation, over 2.1 billion people (*medium confidence*) and about 4 billion people are projected to experience water scarcity (*medium confidence*). At 4°C of warming, the global burned area is projected to increase by 50–70% and the fire frequency by ~30% compared to today (*medium confidence*). {WGII SPM B.4.1, WGII SPM B.4.2, WGII TS.C.1.2, WGII TS.C.2.3, WGII TS.C.4.1, WGII TS.C.4.4} (Figure 3.2, Figure 3.3)

Projected adverse impacts and related losses and damages from climate change escalate with every increment of global warming (*very high confidence*), but they will also strongly depend on socio-economic development trajectories and adaptation actions to reduce vulnerability and exposure (*high confidence*). For example, development pathways with higher demand for food, animal feed, and water, more resource-intensive consumption and production, and limited technological improvements result in higher risks from water scarcity in drylands, land degradation and food insecurity (*high confidence*). Changes in, for example, demography or investments in health systems have effect on a variety of health-related outcomes including heat-related morbidity and mortality (Figure 3.3 Panel d). {WGII SPM B.3, WGII SPM B.4, WGII Figure SPM.3; SRCCL SPM A.6}

With every increment of warming, climate change impacts and risks will become increasingly complex and more difficult to manage. Many regions are projected to experience an increase in the probability of compound events with higher global warming, such as concurrent heatwaves and droughts, compound flooding and fire weather. In addition, multiple climatic and non-climatic risk drivers such as biodiversity loss or violent conflict will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Furthermore, risks can arise from some responses that are intended to reduce the risks of climate change, e.g., adverse side effects of some emission reduction and carbon dioxide removal (CDR) measures (see 3.4.1). (*high confidence*) {WGI SPM C.2.7, WGI Figure SPM.6, WGI TS.4.3; WGII SPM B.1.7, WGII B.2.2, WGII SPM B.5, WGII SPM B.5.4, WGII SPM C.4.2, WGII SPM B.5, WGII CCB2}

Solar Radiation Modification (SRM) approaches, if they were to be implemented, introduce a widespread range of new risks to people and ecosystems, which are not well understood. SRM has the potential to offset warming within one or two decades and ameliorate some climate hazards but would not restore climate to a previous state, and substantial residual or overcompensating climate change would occur at regional and seasonal scales (*high confidence*). Effects of SRM would depend on the specific approach used[65], and a sudden and sustained termination of SRM in a high CO_2 emissions scenario would cause rapid climate change (*high confidence*). SRM would not stop atmospheric CO_2 concentrations from increasing nor reduce resulting ocean acidification under continued anthropogenic emissions (*high confidence*). Large uncertainties and knowledge gaps are associated with the potential of SRM approaches to reduce climate change risks. Lack of robust and formal SRM governance poses risks as deployment by a limited number of states could create international tensions. {WGI 4.6; WGII SPM B.5.5; WGIII 14.4.5.1; Cross-WG box SRM; SR1.5 SPM C.1.4}

[START FIGURE 3.2 HERE]

[65] Several SRM approaches have been proposed, including stratospheric aerosol injection, marine cloud brightening, ground-based albedo modifications, and ocean albedo change. See Annex I: Glossary.

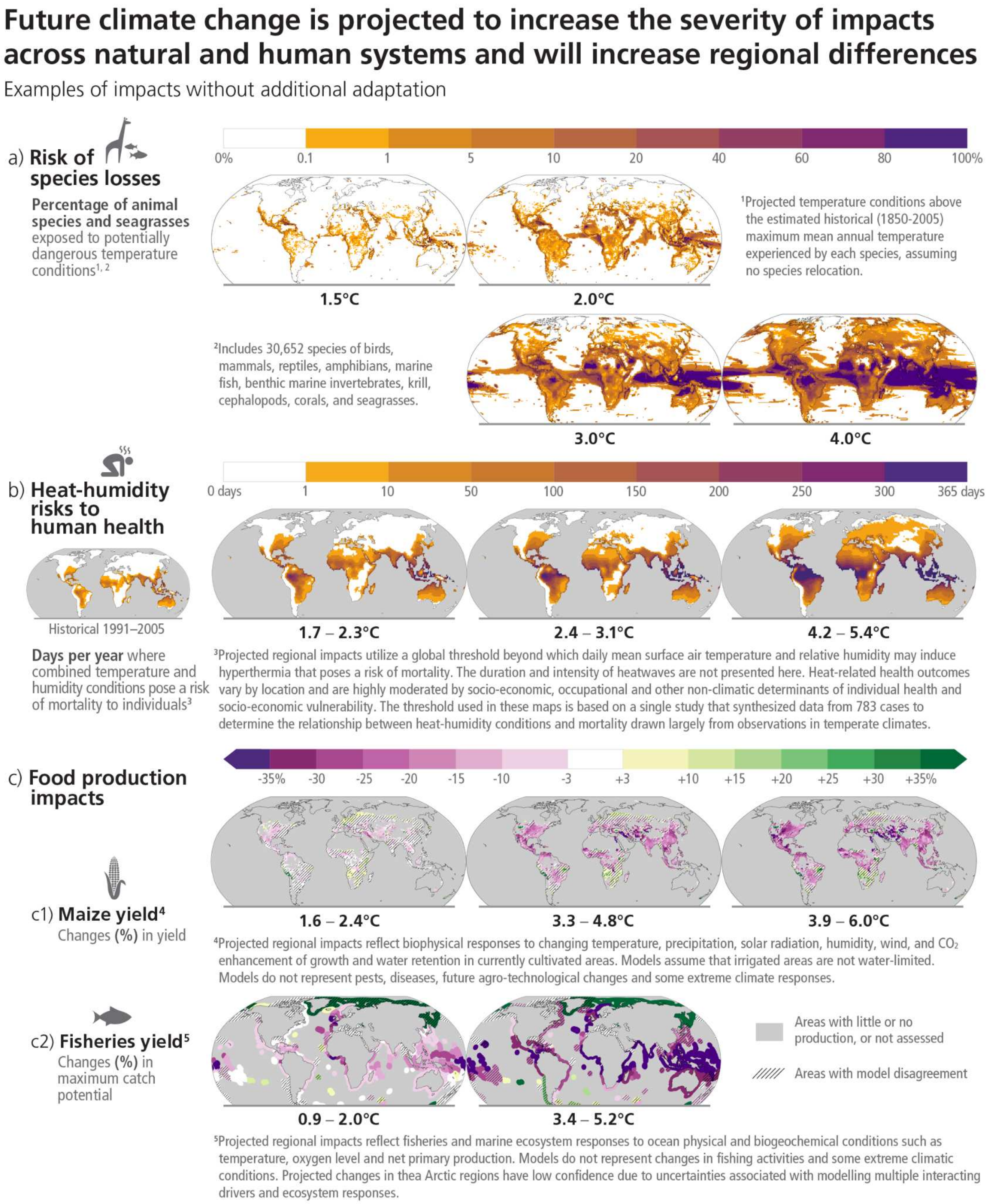


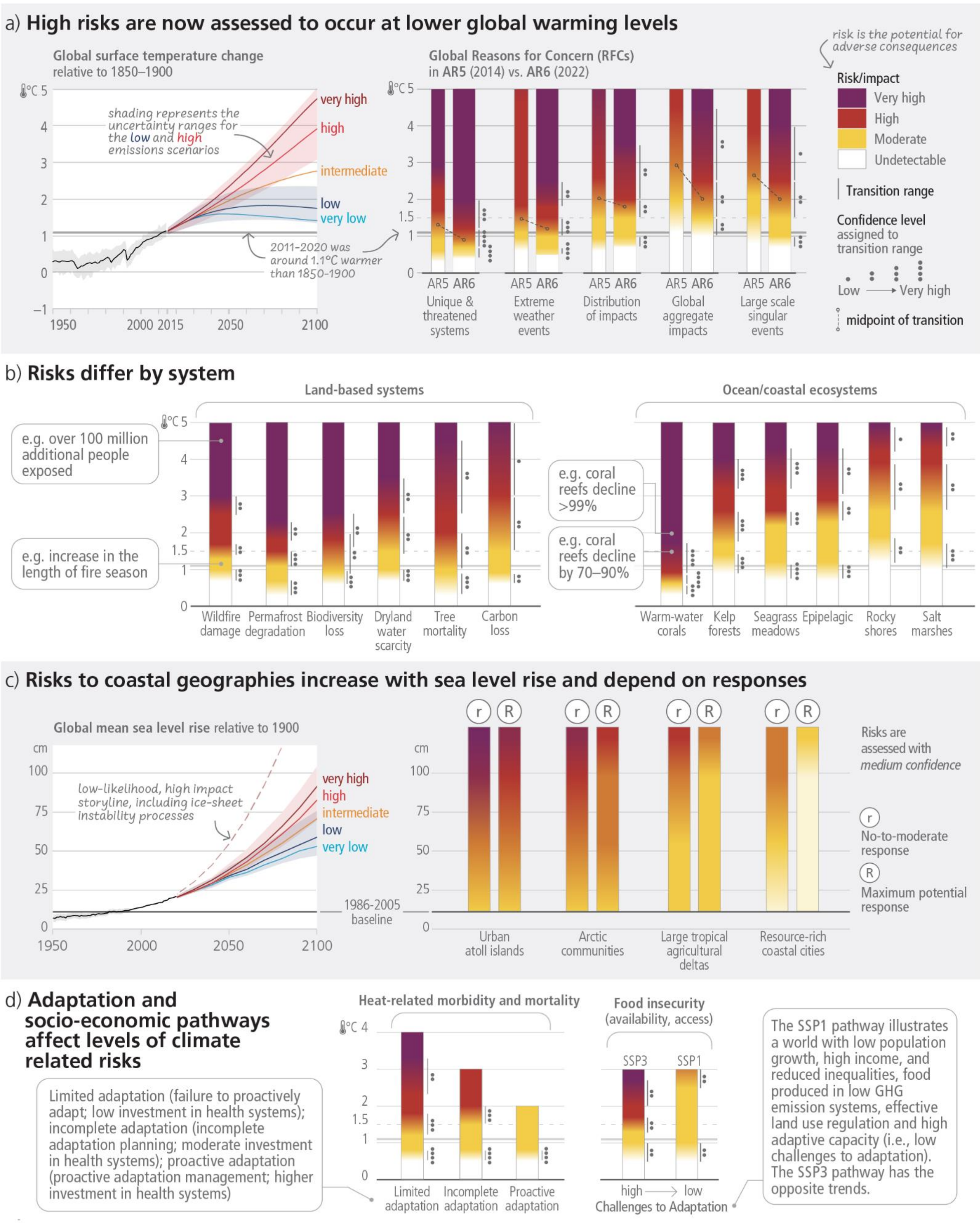
Figure 3.2: Projected risks and impacts of climate change on natural and human systems at different global warming levels (GWLs) relative to 1850–1900 levels. Projected risks and impacts shown on the maps are based on outputs from different subsets of Earth system models that were used to project each impact indicator without additional adaptation. WGII provides further assessment of the impacts on human and natural systems using these projections and additional lines of evidence. **(a)** Risks of species losses as indicated by the percentage of assessed species exposed to potentially dangerous temperature conditions, as defined by conditions beyond the estimated historical (1850-2005) maximum mean annual temperature experienced by each species, at GWLs of 1.5°C, 2°C, 3°C and 4°C. Underpinning projections of temperature are from 21 Earth system models and do not consider extreme events impacting ecosystems such as the Arctic. **(b)** Risk to human health as indicated by the days per year of population exposure to hypothermic conditions that pose a risk of mortality from surface air temperature and humidity conditions for historical period (1991-2005) and at GWLs of 1.7°C–2.3°C (mean = 1.9°C; 13 climate models), 2.4°C–3.1°C (2.7°C; 16 climate models) and 4.2°C–5.4°C (4.7°C; 15 climate models). Interquartile ranges of WGLs by 2081-2100 under RCP2.6, RCP4.5 and

RCP8.5. The presented index is consistent with common features found in many indices included within WGI and WGII assessments. **(c)** Impacts on food production: (c1) Changes in maize yield at projected GWLs of 1.6°C–2.4ºC (2.0°C), 3.3°C–4.8ºC (4.1°C) and 3.9°C–6.0ºC (4.9°C). Median yield changes from an ensemble of 12 crop models, each driven by bias-adjusted outputs from 5 Earth system models from the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). Maps depict 2080–2099 compared to 1986–2005 for current growing regions (>10 ha), with the corresponding range of future global warming levels shown under SSP1-2.6, SSP3-7.0 and SSP5-8.5, respectively. Hatching indicates areas where <70% of the climate-crop model combinations agree on the sign of impact. (c2) Changes in maximum fisheries catch potential by 2081–2099 relative to 1986–2005 at projected GWLs of 0.9°C–2.0°C (1.5°C) and 3.4°C–5.2°C (4.3°C). GWLs by 2081–2100 under RCP2.6 and RCP8.5. Hatching indicates where the two climate-fisheries models disagree in the direction of change. Large relative changes in low yielding regions may correspond to small absolute changes. Biodiversity and fisheries in Antarctica were not analysed due to data limitations. Food security is also affected by crop and fishery failures not presented here {WGII Fig. TS.5, WGII Fig TS.9, WGII Annex I: Global to Regional Atlas Figure AI.15, Figure AI.22, Figure AI.23, Figure AI.29; WGII 7.3.1.2, 7.2.4.1, SROCC Figure SPM.3} (3.1.2, Cross-Section Box.2)

[END FIGURE 3.2 HERE]

[START FIGURE 3.3 HERE]

Risks are increasing with every increment of warming



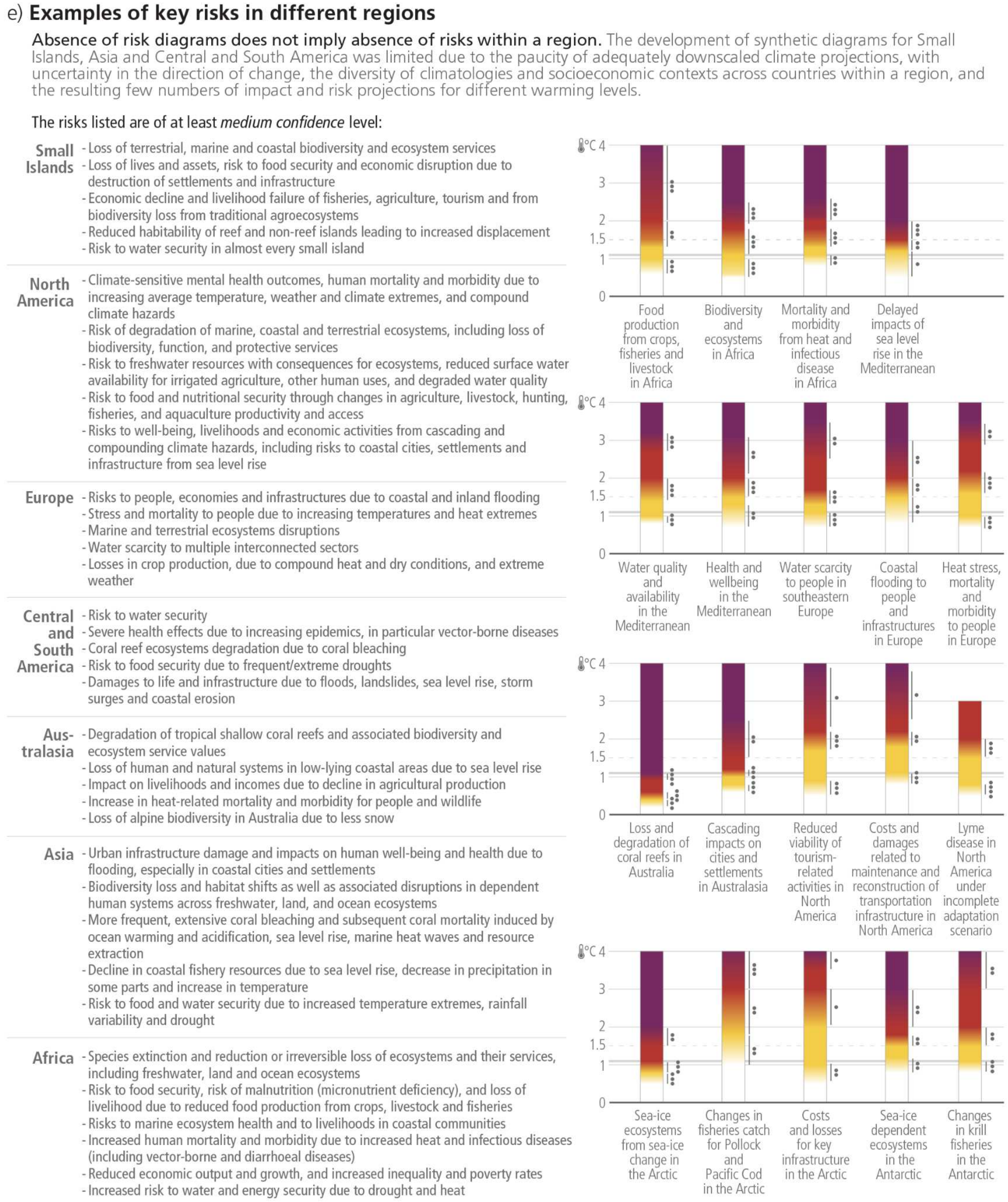


Figure 3.3: Synthetic risk diagrams of global and sectoral assessments and examples of regional key risks. The burning embers result from a literature based expert elicitation. **Panel (a)**: **Left** - Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining CMIP6 model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity. *Very likely* ranges are shown for the low and high GHG emissions scenarios (SSP1-2.6 and SSP3-7.0); **Right** - Global Reasons for Concern, comparing AR6 (thick embers) and AR5 (thin embers) assessments. Diagrams are shown for each RFC, assuming low to no adaptation (i.e., adaptation is fragmented, localised and comprises incremental adjustments to existing practices). However, the transition to a very high risk level has an emphasis on irreversibility and adaptation limits. The horizontal line denotes the present global warming of 1.1°C which is used to separate the observed, past impacts below the line from the future projected risks above it. Lines connect the midpoints of the transition from moderate to high risk across AR5 and AR6. **Panel (b)**: Risks for land-based systems and ocean/coastal ecosystems. Diagrams shown for each

risk assume low to no adaptation. Text bubbles indicate examples of impacts at a given warming level. **Panel (c): Left** - Global mean sea level change in centimetres, relative to 1900. The historical changes (black) are observed by tide gauges before 1992 and altimeters afterwards. The future changes to 2100 (coloured lines and shading) are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models, and *likely* ranges are shown for SSP1-2.6 and SSP3-7.0. **Right** - Assessment of the combined risk of coastal flooding, erosion and salinization for four illustrative coastal geographies in 2100, due to changing mean and extreme sea levels, under two response scenarios, with respect to the SROCC baseline period (1986–2005) and indicating the IPCC AR6 baseline period (1995–2014). The assessment does not account for changes in extreme sea level beyond those directly induced by mean sea level rise; risk levels could increase if other changes in extreme sea levels were considered (e.g., due to changes in cyclone intensity). "No-to-moderate response" describes efforts as of today (i.e., no further significant action or new types of actions). "Maximum potential response" represents a combination of responses implemented to their full extent and thus significant additional efforts compared to today, assuming minimal financial, social and political barriers. The assessment criteria include exposure and vulnerability (density of assets, level of degradation of terrestrial and marine buffer ecosystems), coastal hazards (flooding, shoreline erosion, salinization), in-situ responses (hard engineered coastal defences, ecosystem restoration or creation of new natural buffers areas, and subsidence management) and planned relocation. Planned relocation refers to managed retreat or resettlement. Forced displacement is not considered in this assessment. The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation. **Panel (d)**: **Left** - Heat-sensitive human health outcomes under three scenarios of adaptation effectiveness. The diagrams are truncated at the nearest whole ºC within the range of temperature change in 2100 under three SSP scenarios. **Right** - Risks associated with food security due to climate change and patterns of socio-economic development. Risks to food security include availability and access to food, including population at risk of hunger, food price increases and increases in disability adjusted life years attributable to childhood underweight. Risks are assessed for two contrasted socio-economic pathways (SSP1 and SSP3) excluding the effects of targeted mitigation and adaptation policies. **Panel (e)**: Examples of regional key risks. Risks identified are of at least *medium confidence* level. Key risks are identified based on the magnitude of adverse consequences (pervasiveness of the consequences, degree of change, irreversibility of consequences, potential for impact thresholds or tipping points, potential for cascading effects beyond system boundaries); likelihood of adverse consequences; temporal characteristics of the risk; and ability to respond to the risk, e.g., by adaptation. {WGI Figure SPM.8; WGII SPM B.3.3, WGII Figure SPM.3, WGII SM 16.6, WGII SM 16.7.4; SRCCL Figure SPM.2; SROCC Figure SPM.3d; SROCC SPM.5a; SROCC 4SM; SRCCL 7.3.1; SRCCL 7SM} (CSB.2)

[END FIGURE 3.3 HERE]

3.1.3 The Likelihood and Risks of Abrupt and Irreversible Change

The likelihood of abrupt and irreversible changes and their impacts increase with higher global warming levels (*high confidence*). As warming levels increase, so do the risks of species extinction or irreversible loss of biodiversity in ecosystems such as forests (*medium confidence*), coral reefs (*very high confidence*) and in Arctic regions (*high confidence*). Risks associated with large-scale singular events or tipping points, such as ice sheet instability or ecosystem loss from tropical forests, transition to high risk between 1.5°C–2.5°C (*medium confidence*) and to very high risk between 2.5°C–4°C (*low confidence*). The response of biogeochemical cycles to anthropogenic perturbations can be abrupt at regional scales and irreversible on decadal to century time scales (*high confidence*). The probability of crossing uncertain regional thresholds increases with further warming (*high confidence*). {WGI SPM C.3.2, WGI Box TS.9, WGI TS.2.6; WGII Figure SPM.3, WGII SPM B.3.1, WGII SPM B.4.1, WGII SPM B.5.2, WGII Table TS.1, WGII TS.C.1, WGII TS.C.13.3; SROCC SPM B.4}

Sea level rise is unavoidable for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and sea levels will remain elevated for thousands of years (*high confidence*). Global mean sea level rise will continue in the 21st century (*virtually certain*), with projected regional relative sea level rise within 20% of the global mean along two-thirds of the global coastline (*medium confidence*). The magnitude, the rate, the timing of threshold exceedances, and the long-term commitment of sea level rise depend on emissions, with higher emissions leading to greater and faster rates of sea level rise. Due to relative sea level rise, extreme sea level events that occurred once per century in the recent past are projected to occur at least annually at more than half of all tide gauge locations by 2100 and risks for coastal ecosystems, people and infrastructure will continue to increase beyond 2100 (*high confidence*). At sustained warming levels between 2°C and 3°C, the Greenland and West Antarctic ice sheets will be lost almost completely and irreversibly over multiple millennia (*limited evidence*). The probability and rate of ice mass loss increase with higher global surface temperatures (*high confidence*). Over the next 2000 years, global mean sea level will rise by about 2–3 m if warming is limited to 1.5°C and 2–6 m if limited to 2°C (*low confidence*). Projections of multi-millennial global mean sea level rise are consistent with reconstructed levels during past warm climate periods: global mean sea level was *very likely* 5–25 m higher than today roughly 3 million years ago, when global temperatures were 2.5°C–4°C higher than 1850–1900 (*medium confidence*). Further examples of unavoidable changes in the climate system due to multi-decadal or longer response timescales include continued glacier melt (*very high confidence*) and permafrost carbon loss (*high confidence*). {WGI SPM B.5.2, WGI SPM B.5.3, WGI SPM B.5.4, WGI SPM C.2.5, WGI Box TS.4, WGI Box TS.9, WGI 9.5.1; WGII TS C.5; SROCC SPM B.3, SROCC SPM B.6, SROCC SPM B.9} (Figure 3.4)

The probability of low-likelihood outcomes associated with potentially very large impacts increases with higher global warming levels (*high confidence*). Warming substantially above the assessed *very likely* range for a given scenario cannot be ruled out, and there is *high confidence* this would lead to regional changes greater than assessed in many aspects of the climate system. Low-likelihood, high-impact outcomes could occur at regional scales even for global warming within the *very likely* assessed range for a given GHG emissions scenario. Global mean sea level rise above the *likely* range – approaching 2 m by 2100 and in excess of 15 m by 2300 under a very high GHG emissions scenario (SSP5-8.5) (*low confidence*) – cannot be ruled out due to deep uncertainty in ice-sheet processes[66] and would have severe impacts on populations in low elevation coastal zones. If global warming increases, some compound extreme events[67] will become more frequent, with higher likelihood of unprecedented intensities, durations or spatial extent (*high confidence*). The Atlantic Meridional Overturning Circulation is *very likely* to weaken over the 21st century for all considered scenarios (*high confidence*), however an abrupt collapse is not expected before 2100 (*medium confidence*). If such a low probability event were to occur, it would *very likely* cause abrupt shifts in regional weather patterns and water cycle, such as a southward shift in the tropical rain belt, and large impacts on ecosystems and human activities. A sequence of large explosive volcanic eruptions within decades, as have occurred in the past, is a low-likelihood high-impact event that would lead to substantial cooling globally and regional climate perturbations over several decades {WGI SPM B.5.3, WGI SPM C.3, WGI SPM C.3.1, WGI SPM C.3.2, WGI SPM C.3.3, WGI SPM C.3.4, WGI SPM C.3.5, WGI Figure SPM.8, WGI Box TS.3, WGI Figure TS.6, WGI Box 9.4; WGII SPM B.4.5, WGII SPM C.2.8; SROCC SPM B.2.7}. (Figure 3.4, Cross-Section Box.2)

3.2 Long-term Adaptation Options and Limits

With increasing warming, adaptation options will become more constrained and less effective. At higher levels of warming, losses and damages will increase, and additional human and natural systems will reach adaptation limits. Integrated, cross-cutting multi-sectoral solutions increase the effectiveness of adaptation. Maladaptation can create lock-ins of vulnerability, exposure and risks but can be avoided by long-term planning and the implementation of adaptation actions that are flexible, multi-sectoral and inclusive. (*high confidence*)

The effectiveness of adaptation to reduce climate risk is documented for specific contexts, sectors and regions (*high confidence*) and will decrease with increasing warming (*high confidence*)[68]. For example, common adaptation responses in agriculture – adopting improved cultivars and agronomic practices, and changes in cropping patterns and crop systems – will become less effective from 2°C to higher levels of warming (*high confidence*). The effectiveness of most water-related adaptation options to reduce projected risks declines with increasing warming (*high confidence*). Adaptations for hydropower and thermo-electric power generation are effective in most regions up to 1.5°C–2°C, with decreasing effectiveness at higher levels of warming (*medium confidence*). Ecosystem-based Adaptation is vulnerable to climate change impacts, with effectiveness declining with increasing global warming (*high confidence*). Globally, adaptation options related to agroforestry and forestry have a sharp decline in effectiveness at 3°C, with a substantial increase in residual risk (*medium confidence*). {WGII SPM C.2, WGII SPM C.2.1, WGII SPM C.2.5, WGII SPM C.2.10, WGII Figure TS.6 Panel (e), 4.7.2}

---

[66] This outcome is characterised by deep uncertainty: Its likelihood defies quantitative assessment but is considered due to its high potential impact. {WGI Box TS.1; WGII Cross-Chapter Box DEEP}

[67] See Annex I: Glossary. Examples of compound extreme events are concurrent heatwaves and droughts or compound flooding. {WGI SPM Footnote 18}

[68] There are limitations to assessing the full scope of adaptation options available in the future since not all possible future adaptation responses can be incorporated in climate impact models, and projections of future adaptation depend on currently available technologies or approaches. {WGII 4.7.2}

With increasing global warming, more limits to adaptation will be reached (*high confidence*) and losses and damages, strongly concentrated among the poorest vulnerable populations, will increase (*high confidence*). Already below 1.5°C, autonomous and evolutionary adaptation responses by terrestrial and aquatic ecosystems will increasingly face hard limits (*high confidence*) (Section 2.1.2). Above 1.5°C, some ecosystem-based adaptation measures will lose their effectiveness in providing benefits to people as these ecosystems will reach hard adaptation limits (*high confidence*). Adaptation to address the risks of heat stress, heat mortality and reduced capacities for outdoor work for humans face soft and hard limits across regions that become significantly more severe at 1.5°C, and are particularly relevant for regions with warm climates (*high confidence*). Above 1.5°C global warming level, limited freshwater resources pose potential hard limits for Small Islands and for regions dependent on glacier and snow melt (*medium confidence*). By 2°C, soft limits are projected for multiple staple crops, particularly in tropical regions (*high confidence*). By 3°C, soft limits are projected for some water management measures for many regions, with hard limits projected for parts of Europe (*medium confidence*). {WGII SPM C.3, WGII SPM C.3.3, WGII SPM C.3.4, WGII SPM C.3.5, WGII TS.D.2.2, WGII TS.D.2.3; SR1.5 SPM B.6; SROCC SPM C.1}

Integrated, cross-cutting multi-sectoral solutions increase the effectiveness of adaptation. For example, inclusive, integrated and long-term planning at local, municipal, sub-national and national scales, together with effective regulation and monitoring systems and financial and technological resources and capabilities foster urban and rural system transition. There are a range of cross-cutting adaptation options, such as disaster risk management, early warning systems, climate services and risk spreading and sharing that have broad applicability across sectors and provide greater benefits to other adaptation options when combined. Transitioning from incremental to transformational adaptation, and addressing a range of constraints, primarily in the financial, governance, institutional and policy domains, can help overcome soft adaptation limits. However, adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits. (*high confidence*) {WGII SPM C.2, WGII SPM C.2.6, WGII SPM.C.2.13, WGII SPM C.3.1, WGII SPM.C.3.4, WGII SPM C.3.5, WGII Figure TS.6 Panel (e)}

Maladaptive responses to climate change can create lock-ins of vulnerability, exposure and risks that are difficult and expensive to change and exacerbate existing inequalities. Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation. Adaptation options can become maladaptive due to their environmental impacts that constrain ecosystem services and decrease biodiversity and ecosystem resilience to climate change or by causing adverse outcomes for different groups, exacerbating inequity. Maladaptation can be avoided by flexible, multi-sectoral, inclusive and long-term planning and implementation of adaptation actions with benefits to many sectors and systems. (*high confidence*) {WGII SPM C.4, WGII SPM.C.4.1, WGII SPM C.4.2, WGII SPM C.4.3}

Sea level rise poses a distinctive and severe adaptation challenge as it implies both dealing with slow onset changes and increases in the frequency and magnitude of extreme sea level events (*high confidence*). Such adaptation challenges would occur much earlier under high rates of sea level rise (*high confidence*). Responses to ongoing sea level rise and land subsidence include protection, accommodation, advance and planned relocation (*high confidence*). These responses are more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values and underpinned by inclusive community engagement processes (*high confidence*). Ecosystem-based solutions such as wetlands provide co-benefits for the environment and climate mitigation, and reduce costs for flood defences (*medium confidence*), but have site-specific physical limits, at least above 1.5ºC of global warming (*high confidence)* and lose effectiveness at high rates of sea level rise beyond 0.5–1 cm/yr (*medium confidence*). Seawalls can be maladaptive as they effectively reduce impacts in the short term but can also result in lock-ins and increase exposure to climate risks in the long term unless they are integrated into a long-term adaptive plan (*high confidence*). {WGI SPM C.2.5; WGII SPM C.2.8, WGII SPM C.4.1; WGII 13.10, WGII Cross-Chapter Box SLR; SROCC SPM B.9, SROCC SPM C.3.2, SROCC Figure SPM.4, SROCC Figure SPM.5c} (Figure 3.4)

[START FIGURE 3.4 HERE]

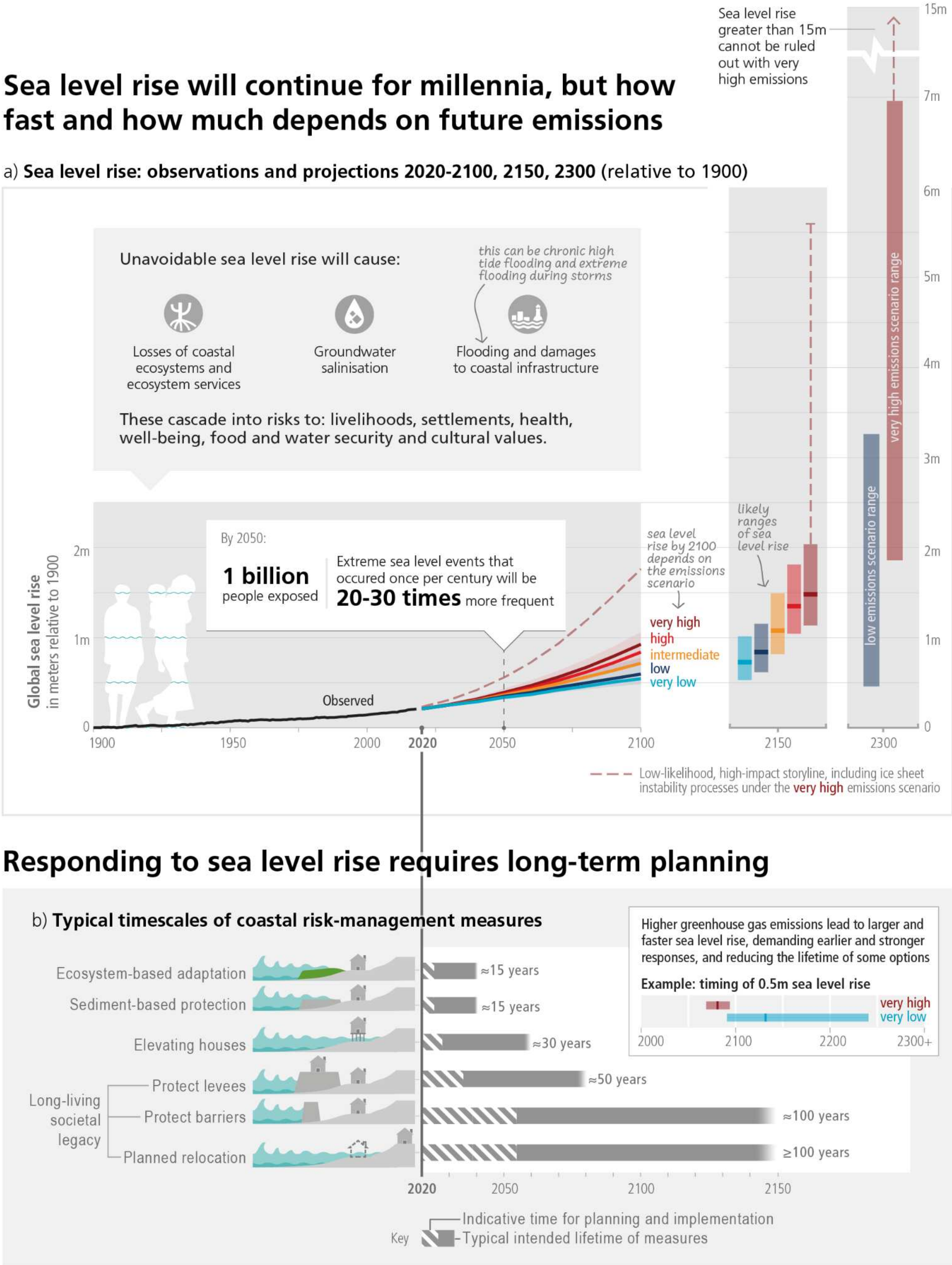


Figure 3.4: Observed and projected global mean sea level change and its impacts, and time scales of coastal risk management. Panel (a): Global mean sea level change in metres relative to 1900. The historical changes (black) are observed by tide gauges before 1992 and altimeters afterwards. The future changes to 2100 and for 2150 (coloured lines and shading) are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models, and median values and *likely* ranges are shown for the considered scenarios. Relative to 1995–2014, the *likely* global mean sea level rise by 2050 is between 0.15–0.23 m in the very low GHG emissions scenario (SSP1-1.9) and 0.20–0.29 m in the very high GHG emissions scenario (SSP5-8.5); by 2100 between 0.28–0.55 m under SSP1-1.9 and 0.63–1.01 m under SSP5-8.5; and by 2150 between 0.37–0.86 m under SSP1-1.9 and 0.98–1.88 m under SSP5-8.5 (*medium*

confidence). Changes relative to 1900 are calculated by adding 0.158 m (observed global mean sea level rise from 1900 to 1995–2014) to simulated changes relative to 1995–2014. The future changes to 2300 (bars) are based on literature assessment, representing the 17th–83rd percentile range for SSP1-2.6 (0.3–3.1 m) and SSP5-8.5 (1.7–6.8 m). Red dashed lines: Low-likelihood, high-impact storyline, including ice sheet instability processes. These indicate the potential impact of deeply uncertain processes, and show the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact processes that cannot be ruled out; because of *low confidence* in projections of these processes, this is not part of a *likely* range. IPCC AR6 global and regional sea level projections are hosted at https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool. The low-lying coastal zone is currently home to around 896 million people (nearly 11% of the 2020 global population), projected to reach more than one billion by 2050 across all five SSPs. **Panel (b)**: Typical time scales for the planning, implementation (dashed bars) and operational lifetime of current coastal risk-management measures (blue bars). Higher rates of sea level rise demand earlier and stronger responses and reduce the lifetime of measures (inset). As the scale and pace of sea level rise accelerates beyond 2050, long-term adjustments may in some locations be beyond the limits of current adaptation options and for some small islands and low-lying coasts could be an existential risk. {WGI SPM B.5, C.2.5, Figure SPM.8, 9.6; WGII SPM B.4.5, B.5.2, C.2.8, D.3.3, TS.D.7, Cross-Chapter Box SLR} (CSB.2)

[END FIGURE 3.4 HERE]

3.3 Mitigation Pathways

Limiting human-caused global warming requires net zero anthropogenic CO_2 emissions. Pathways consistent with 1.5°C and 2°C carbon budgets imply rapid, deep, and in most cases immediate GHG emission reductions in all sectors (*high confidence*). Exceeding a warming level and returning (i.e. overshoot) implies increased risks and potential irreversible impacts; achieving and sustaining global net negative CO_2 emissions would reduce warming (*high confidence*).

3.3.1 Remaining Carbon Budgets

Limiting global temperature increase to a specific level requires limiting cumulative net CO_2 emissions to within a finite carbon budget[69], along with strong reductions in other GHGs. For every 1000 $GtCO_2$ emitted by human activity, global mean temperature rises by *likely* 0.27°C–0.63°C (best estimate of 0.45°C). This relationship implies that there is a finite carbon budget that cannot be exceeded in order to limit warming to any given level. {WGI SPM D.1, WGI SPM D.1.1; SR1.5 SPM C.1.3} (Figure 3.5)

The best estimates of the remaining carbon budget (RCB) from the beginning of 2020 for limiting warming to 1.5°C with a 50% likelihood[70] is estimated to be 500 $GtCO_2$; for 2°C (67% likelihood) this is 1150 $GtCO_2$.[71] Remaining carbon budgets have been quantified based on the assessed value of TCRE and its uncertainty, estimates of historical warming, climate system feedbacks such as emissions from thawing permafrost, and the global surface temperature change after global anthropogenic CO_2 emissions reach net zero, as well as variations in projected warming from non-CO_2 emissions due in part to mitigation action. The stronger the reductions in non-CO_2 emissions the lower the resulting temperatures are for a given RCB or the larger RCB for the same level of temperature change. For instance, the RCB for limiting warming to 1.5°C with a 50% likelihood could vary between 300 to 600 $GtCO_2$ depending on non-CO_2 warming[72]. Limiting warming to 2°C with a 67% (or 83%) likelihood would imply a RCB of 1150 (900) $GtCO_2$ from the beginning

[69] See Annex 1: Glossary.
[70] This likelihood is based on the uncertainty in transient climate response to cumulative net CO_2 emissions and additional Earth system feedbacks and provides the probability that global warming will not exceed the temperature levels specified. {WGI Table SPM.1}
[71] Global databases make different choices about which emissions and removals occurring on land are considered anthropogenic. Most countries report their anthropogenic land CO_2 fluxes including fluxes due to human-caused environmental change (e.g., CO_2 fertilisation) on 'managed' land in their National GHG inventories. Using emissions estimates based on these inventories, the remaining carbon budgets must be correspondingly reduced. {WGIII SPM Footnote 9, WGIII TS.3, WGIII Cross-Chapter Box 6}
[72] The central case RCB assumes future non-CO_2 warming (the net additional contribution of aerosols and non-CO_2 GHG) of around 0.1°C above 2010–2019 in line with stringent mitigation scenarios. If additional non-CO_2 warming is higher, the RCB for limiting warming to 1.5°C with a 50% likelihood shrinks to around 300 $GtCO_2$. If, however, additional non-CO_2 warming is limited to only 0.05°C (via stronger reductions of CH_4 and N_2O through a combination of deep structural and behavioural changes, e.g., dietary changes), the RCB could be around 600 $GtCO_2$ for 1.5°C warming. {WGI Table SPM.2, WGI Box TS.7; WGIII Box 3.4}