International Actuarial Association
Association Actuarielle Internationale

Climate Science: A Summary for Actuaries

What the IPCC Climate Change Report 2021 Means for the Actuarial Profession

March 2022

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This paper was prepared by the Climate Risk Task Force of the International Actuarial Association (IAA) and the Working Group I Technical Support Unit of the Intergovernmental Panel on Climate Change (IPCC).

The IAA is the worldwide association of professional actuarial associations, with several special interest sections and working groups for individual actuaries. The IAA exists to encourage the development of a global profession, acknowledged as technically competent and professionally reliable, which will ensure that the public interest is served.

The IPCC is the United Nations body for assessing the science related to climate change. Working Group I of the IPCC assesses the physical science of climate change.

This paper has been approved for IAA publication by the Climate Risk Task Force and the Executive Committee in accordance with the IAA's Communications Policy with the consent of the IPCC Working Group I Technical Support Unit.

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Introduction

This Summary, based on the IPCC Sixth Assessment Report, is tailored to the actuarial community. It has been co-developed by the authors of the IPCC report and a team of actuaries and catastrophe experts from the IAA. The scientific data and conclusions are attributed alone to the IPCC, while the need for emphasis on some risks, and the comments about actuarial practices have been provided by the IAA team.

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. Now in its sixth assessment cycle, the IPCC comprises three Working Groups. The Working Group I (WGI) contribution to the Sixth Assessment Report (AR6) addresses the **physical understanding of the climate system and climate change**. It brings together the latest advances in climate science and combines multiple lines of evidence from observations, paleoclimate, process understanding and global and regional climate simulations to get the clearest picture of past, present and possible future climate. Released in August 2021, the report is based on the research of thousands of scientists worldwide from more than 14,000 scientific studies. A team of more than 234 scientists from 65 countries worked together for over three years to deliver the report. The WGI Sixth Assessment Report key findings include:

- For decades, we have known that the world is warming. Recent changes in the climate are widespread, rapid, and intensifying. They are unprecedented in thousands of years.
- It is indisputable that human activities are causing climate change. Human influence is making extreme climate events, including heatwaves, heavy rainfall, and droughts, more frequent and severe.
- Climate change is already affecting every region on Earth, in multiple ways. Its effects will increase with further warming.
- There is no going back from some changes in the climate system. However, some of these changes could be slowed and others could be stopped by limiting future warming.
- Unless there are immediate, rapid, and large-scale reductions in greenhouse gas emissions, limiting global warming to 1.5°C or even 2°C relative to 1850–1900 (pre-industrial levels) will not be possible.
- To limit global warming, strong, rapid, and sustained reductions in emissions of carbon dioxide, methane, and other greenhouse gases are necessary. This would not only reduce the consequences of climate change but also improve air quality.

The second and third installments of the IPCC Sixth Assessment Report are scheduled for release in the first half of 2022 and will cover the *Impacts, Adaptation and Vulnerability* (Working Group II) and *Mitigation of Climate Change* (Working Group III), respectively.

Actuaries, as risk professionals, need to understand the physical impacts of climate systems and climate changes. Such impacts will affect how risks are underwritten, priced, managed, and reported, whether for general insurance, life insurance, pensions, other financial institutions, and social security. It is important for actuaries to understand the magnitude of the potential changes, the uncertainty of their frequency and intensity, and the inherent volatility of such risks. Actuaries can no longer rely on past experience to assess risks without taking into account the potential impacts of climate change.

Actuaries are particularly interested in the effect of climate change on floods, droughts, fires, storms, and air pollution, but each of the physical changes analyzed in the latest IPCC Working Group I report could have an impact on human well-being and the long-term sustainability of the environment. This summary, however, focuses on the physical changes affecting the most common perils analysed by actuaries. This summary is supplemented with two Annexes on data and regional specificities (Annex.I) and a glossary that contains definitions for any text shown in green (Annex.II).

IPCC Calibrated Language to Communicate Level of Certainty

All IPCC Sixth Assessment Reports follow the same approach to communicate the degree of certainty associated with a specific finding, as described in the 'Guidance Notes for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties'. Author teams use two metrics to communicate the degree of certainty in key findings:

1. Confidence: a qualitative measure of the validity of a finding, based on the type, amount, quality and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement.
2. Likelihood: a quantitative measure of uncertainty in a finding, expressed probabilistically (e.g., based on statistical analysis of observations or model results, or both, and on expert judgment by the IPCC author team or from a formal quantitative survey of expert views, or both).

Throughout IPCC reports, the calibrated language indicating a formal confidence/likelihood assessment is clearly identified by italics (e.g., *medium confidence*). Where appropriate, findings can also be formulated as statements of fact without uncertainty qualifiers. This Summary for Actuaries also includes these calibrated language terms as stated in the main Working Group I Sixth Assessment Report.

Confidence

The following summary terms are used to describe the available *evidence: limited, medium, or robust*; and the degree of agreement: *low, medium,* or *high*. Generally, evidence is most robust when there are multiple, consistent, independent lines of high-quality evidence. If there is sufficient evidence and agreement, the level of *confidence* can be evaluated. The assessed level of confidence is expressed using five qualifiers: *very low, low, medium, high,* and *very high*. Low confidence does not imply distrust in the finding; instead, it means that the statement is the best conclusion based on the available evidence and knowledge.

Likelihood

If the expert judgment of the IPCC author team concludes that there is sufficient *confidence* and quantitative or probabilistic *evidence*, assessment conclusions can be expressed with likelihood statements. Terms used to indicate the assessed likelihood of an outcome are shown in Table 1.

Table 1. IPCC calibrated terms used to indicate the assessed likelihood of an outcome. This table is sourced from the 'Guidance Notes for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties'.

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

The Working Group I Sixth Assessment Report also uses low-likelihood outcomes that cannot be ruled out but whose impact would be substantial if they were to occur. These instances of deep uncertainty are described in the Future global climate changes section of this summary.

For more information see Working Group I Sixth Assessment Report Chapter 1, Box1.1 or the Guidance Note on Uncertainty (https://www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf).

Climate Change Today

Human Influence on the Climate System is Now Unequivocal

Global surface temperature is now 1.07°C higher than in the pre-industrial period (1850-1900), with larger increases over land (1.59°C) than over the ocean (0.88°C). The Working Group I Sixth Assessment Report concludes that **all** of the observed warming is a consequence of human activities (Figure 1, see also Box: Attributing Climate Change in this summary). Over this time frame, well-mixed greenhouse gas emissions (dominated by carbon dioxide and, to a lesser extent, methane) contributed a warming of 1.0°C to 2.0°C, some other emissions from human activities, such as air pollutants known as aerosols, caused a cooling, but the magnitude of this effect was only 0.0°C to 0.8°C. Natural drivers of the climate changed global surface temperature by –0.1°C to 0.1°C, and internal variability changed it by –0.2°C to 0.2°C[1]. Climate model simulations of global temperature only match the observational record when human-caused emissions are included (Figure 1).

For more information, see the Summary for Policymakers Section A.1 and the Technical Summary Cross-Section Box TS.1.

Recent Changes in Climate are Widespread, Rapid, and Intensifying. Their Magnitude and Scale are Unprecedented in Thousands of Years.

Human influence is assessed to be the main driver[2] of atmosphere (*very likely*) and ocean (*extremely likely*) warming, ocean acidification (*virtually certain*), loss of Arctic sea ice (*very likely*), decreased Northern hemisphere spring snow cover (*very likely*), the global retreat of glaciers (*very likely*), and Greenland Ice Sheet mass loss (*very likely*). Human influence is the main driver of sea level rise (*very likely*) resulting principally from the loss of glaciers and other land ice and from thermal expansion of seawater as it warms. Human influence has also contributed to the pattern of observed changes in precipitation (*likely*) and near-surface ocean salinity (*extremely likely*), as well as the observed loss of oxygen in the ocean (*medium confidence*). Human influence has also contributed to monsoon changes, with decreases in monsoon precipitation due to the cooling effect of aerosol emissions counteracting the increase in monsoon precipitation resulting from rising greenhouse gas concentrations (*medium confidence*). This shows how air pollution can modify some climate changes at the regional scale.

1 All ranges here are assessed to be *likely*.

2 Main driver = responsible for more than 50% of the change.

For more information see the Summary for Policymakers Section A.1 and the Technical Summary Section TS.2.3 (air), TS.2.4 (ocean), TS2.5 (cryosphere), Box TS.6 (water cycle), and Box TS.13 (monsoons).

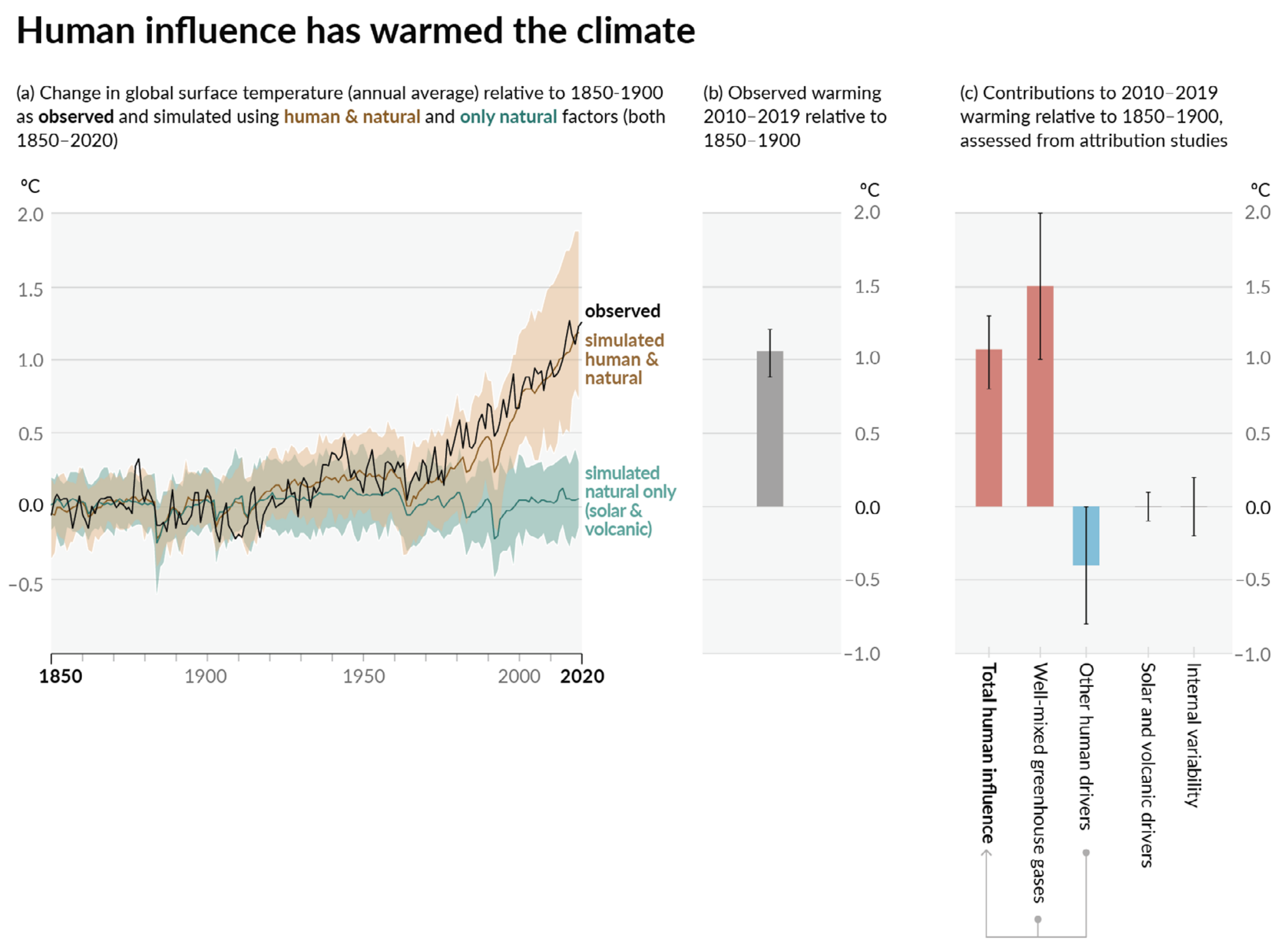


Figure 1: Observed warming is caused by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling. Panel (a): Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to Coupled Model Intercomparison Project Phase 6 (CMIP6) climate model simulations of the temperature response to both human and natural drivers (brown), and to only natural drivers (solar and volcanic activity, green). Solid coloured lines show the multi-model average, and coloured shades show the *very likely* range of simulations. Panel (b): The grey bar shows the observed increase of global surface temperature in 2010–2019 relative to 1850–1900 and its very *likely* range (black error bar). Panel (c): Temperature change in 2010–2019 relative to 1850–1900 attributed to total human influence, change in well-mixed greenhouse gases concentrations, other human drivers (aerosols, ozone, and land-use change), natural drivers (solar and volcanic), and internal climate variability and their *likely* ranges (black error bars). This figure is adapted from the Summary for Policymakers Figures SPM.1 and SPM.2.

Many of these changes are unprecedented in hundreds, thousands, or millions of years:

- Global temperatures are warming at a rate that is unprecedented in the last 2000 years (*high confidence*).
- Atmospheric carbon dioxide concentrations are at their highest in the last 2 million years (*high confidence*).
- Methane and nitrous oxide atmospheric concentrations are at their highest in 800,000 years (*very high confidence*).
- Ocean warming is the fastest in at least 11,000 years (*medium confidence*).
- The rate of sea level rise since 1900 is unprecedented in at least 3000 years (*high confidence*).
- Ocean heat uptake is at its fastest in the last 11,000 years (*medium confidence*).
- Ocean acidification is unusual in the last 2 million years (*medium confidence*).
- Summer Arctic sea ice area is at its lowest level in at least 1000 years (*medium confidence*).
- The retreat of glaciers on a global scale since 1950 is unprecedented in at least 2000 years (*medium confidence*).

For more information see the Summary for Policymakers Section A.2 and the Technical Summary Section TS.2.

Climate Change is Already Affecting Every Region on Earth, in Multiple Ways.

Human-caused climate changes are increasingly evident at regional and local scales. The clear signal of human-caused climate change is now discernible from natural variability in the temperature trends observed across almost all land regions (similar figures to Figure 1 panel a) can be seen for all continental regions in the Technical Summary Figure TS.7). Warming is stronger over the land compared to over the ocean and strongest in the Arctic. This is because the ocean has a larger heat capacity than the land, which means that more heat energy is required to raise its temperature by a given amount. Year-to-year variations in temperature are smallest in the tropics, so the warming trend is relatively more apparent there compared to the range of past observations (Figure 2).

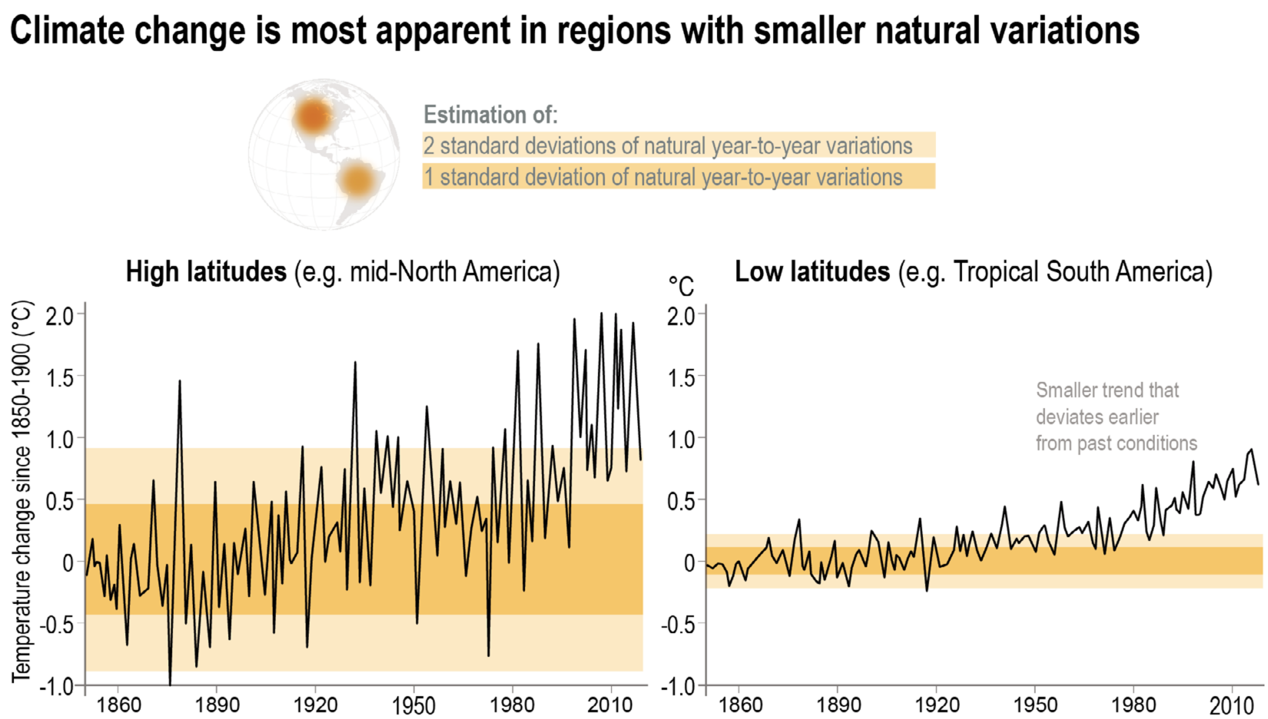


Figure 2: The observed temperature change was seen earlier in the tropics than the mid-latitudes, even though the changes were of a smaller magnitude. Regions at high latitudes have warmed by a larger amount than regions at lower latitudes but they also have much larger natural variations. This figure is adapted from Chapter 1 FAQ 1.4, Figure 1.

For more information see the Technical Summary Section TS.1.2.3 and Chapter 1 FAQ 1.4.

Attributing Climate Change

Attributing the causes of climate change can mean different things in different contexts. In this summary, attribution refers to two main concepts:

Attribution of observed climate change to human influence: This refers to detected changes in large-scale/global climate variables (e.g., global mean temperature) that can be attributed to human and/or natural forcings. A range of methods are used to answer questions such as: 'To what degree is an observed change in global temperature induced by human-caused greenhouse gas and aerosol concentration changes, or influenced by natural variability?'. These questions can be answered, for example, by using fingerprint analyses that compare observations with climate simulations that take into account only natural drivers or natural and human drivers (Figure 1).

Attribution of weather and climate extreme events to human influence: Methods are also available to attribute the change in likelihood or characteristics of specific regional weather or climate events or classes of events to underlying drivers, including human influence. Questions might include: 'Have human-driven greenhouse gas emissions increased the likelihood or intensity of an observed heatwave?'. Extreme events where an attributable human influence have been identified include hot and cold temperature extremes (including some with widespread impacts), heavy precipitation events, and certain types of droughts, and tropical cyclones.

Climate change attribution can serve to evaluate and communicate links associated with climate change, inform and constrain projections, inform mitigation and litigation decisions as well as inform risk management and adaptation planning.

For more information see Chapter 1 Cross-Working Group Box 1.1 and Chapter 3 (for observed climate change attribution), and Chapters 10 and 11 (for extremes attribution).

Human Influence is Already Making Many Extreme Climate Events, Including Heatwaves, Heavy Rainfall, and Droughts, More Frequent and Severe.

Figure 3 shows that climate change is already affecting every inhabited region across the globe. Using hot extremes, heavy precipitation and agricultural and ecological drought as examples, the figure shows human influence contributing to many observed changes in weather and climate extremes (see the Box: Attributing Climate Change in this summary). These climate changes can have direct implications for society. For example, a warmer climate increases the amount and intensity of rainfall during wet events, which is relevant for flood risk. However, the link between rainfall and flooding is complex, so while the most severe flooding events are expected to worsen, floods could become rarer in some regions. The IPCC Working Group II report provides updated information on the impacts of climate change on socio-economic and natural systems.

Since the 1950s, hot extremes (including heatwaves) have become more frequent and more intense across almost all land regions, while cold extremes (including cold waves) have become less frequent and less severe. Globally, 1-in-50-year[3] hot extreme events of the preindustrial period have become about five times more likely due to human activities, and 1-in-10-year events almost three times more likely. Some recent hot extremes and heavy rainfall events would have been extremely unlikely without human influence. The frequency and intensity of heavy precipitation events have increased in most regions. Agricultural and ecological droughts have become more severe in several regions due to increased land evapotranspiration and in some regions a decrease in rainfall. There is currently low confidence in the role of amplified Arctic warming on mid-latitude temperatures (particularly extreme cold temperatures). Future climate change could affect mid-latitude variability in a number of ways, but this is still to be clarified as contrasting lines of evidence are yet to be reconciled.

For more information see the Summary for Policymakers Section A.3, the Technical Summary Section TS.2.6, Chapter 10 Cross-Chapter Box 10.1 and Chapter 11.

3 Such as an event only expected to occur on average once every 50 years.

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

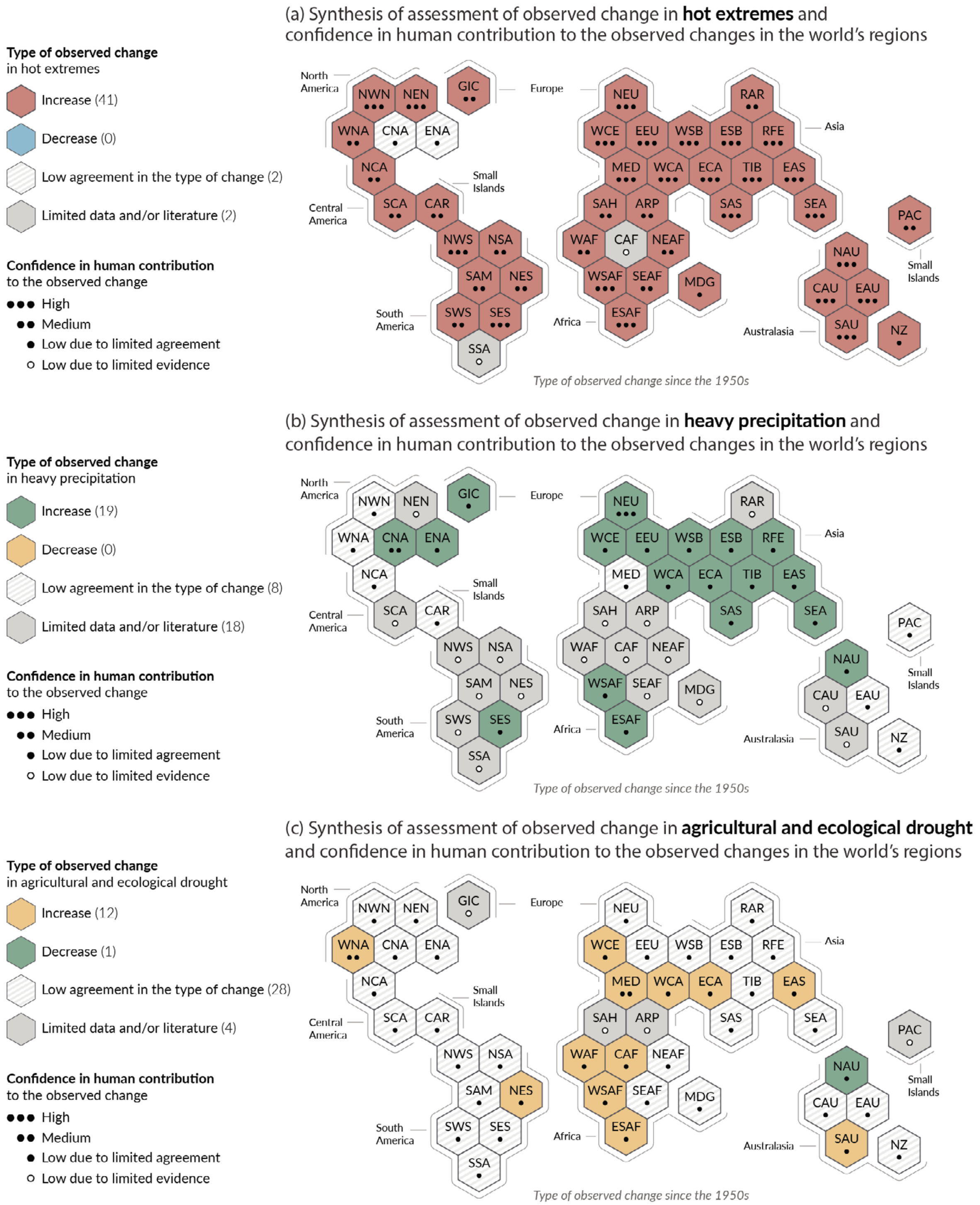


Figure 3: Synthesis of assessed observed and attributable regional changes for hot extremes (a), heavy precipitation (b) and agricultural and ecological drought (c). The inhabited regions as defined in the IPCC Working Group I Sixth Assessment Report are displayed as hexagons with identical

size in their approximate geographical location (see legend Figure 10 for regional acronyms). All assessments are made for the 1950s to the present. White and light grey striped hexagons are used where there is *low agreement* in the type of change for the region as a whole, and grey hexagons are used when there is limited data and/or literature that prevents an assessment of the region as a whole. Other colours indicate at least *medium confidence* in the observed change. The confidence level for the human influence on these observed changes is based on assessing trend detection and attribution and event attribution literature, and it is indicated by the number of dots. Panel (a) For hot extremes, the evidence is mostly drawn from changes in metrics based on daily maximum temperatures; regional studies using other indices (heatwave duration, frequency and intensity) are used in addition. Panel (b) For heavy precipitation, the evidence is mostly drawn from changes in indices based on one-day or five-day precipitation amounts using global and regional studies. Panel (c) Agricultural and ecological droughts are assessed based on observed and simulated changes in total column soil moisture, complemented by evidence on changes in surface soil moisture, water balance (precipitation minus evapotranspiration) and indices driven by precipitation and atmospheric evaporative demand. See Section Future Regional Climate Changes of this summary for more information on the Working Group I Sixth Assessment Report regions. This figure is adapted from the Summary for Policymakers Figure SPM.3.

Marine heatwaves have become more frequent over the 20th century, approximately doubling since the 1980s (*high confidence*) and becoming more intense (*medium confidence*). Human influence has *very likely* contributed to most marine heatwaves since at least 2006.

Regional sea level change has been the main driver of changes in extreme water levels across the tide gauge network over the 20th century. Observations show that high tide flooding events that occurred five times per year during 1960–1980 occurred on average more than eight times per year during 1995–2014. (*high confidence*)

Although there has been no overall increase in the annual number of tropical cyclones, they are now *likely* stronger (the proportion of Category 3–5 tropical cyclones has increased over the last four decades). The global frequency of TC rapid intensification events has *likely* increased over the past four decades. The strongest tropical cyclones in the western North Pacific (the location of their peak intensity) have *very likely* shifted northward. While there is *high confidence* for increased tropical cyclones precipitation, there is limited evidence so far for human influence on this overall trend. However, there is *high confidence* that human influence contributed to extreme rainfall amounts during some specific tropical cyclones and hurricanes, such as Hurricane Harvey (2017). The average and maximum rain rates associated with TCs, extratropical cyclones and atmospheric rivers across the globe, and severe convective storms in some regions, increase in a warming world (*high confidence*). For extratropical cyclones over both hemispheres, there is *low confidence* in changes to the tracks (paths) over which these storms move, but storm tracks over both hemispheres have shifted towards the poles since the 1980s (*medium confidence*). Figure 4 shows how storms are changing with increasing global warming.

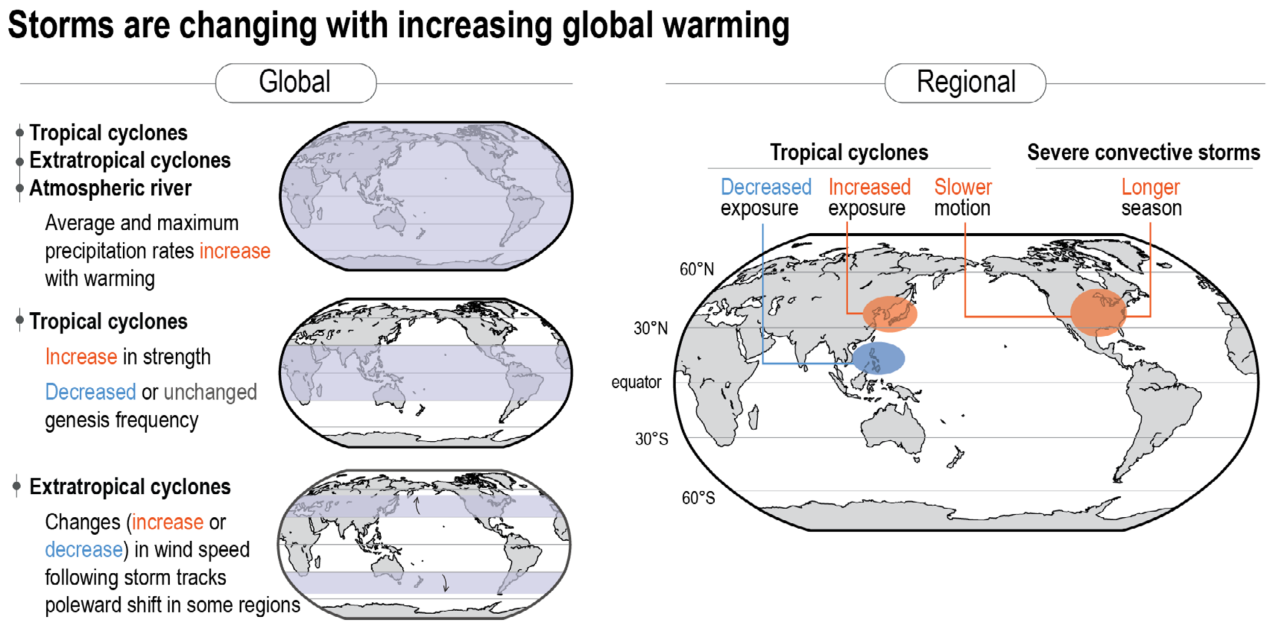


Figure 4: Summary schematic of past and projected changes in tropical cyclone (TC), extratropical cyclone (ETC), atmospheric river (AR), and severe convective storm (SCS) behaviour. Global changes (blue shading in left panels) from top to bottom: 1) Increased mean and maximum rain-rates in TCs, ETCs, and ARs [past (*low confidence* due to lack of reliable data) and projected (*high confidence*)]. 2) Increased proportion of stronger TCs [past (*medium confidence*) and projected (*high confidence*)]. 3) Decrease or no change in global frequency of TC genesis [past (*low confidence* due to lack of reliable data) and projected (*medium confidence*)]. 4) Increased and decreased ETC wind-speed, depending on the region, as storm tracks change [past (*low confidence* due to lack of reliable data) and projected (medium confidence)]. Regional changes (right panel), from left to right: 1) Poleward TC migration in the western North Pacific and subsequent changes in TC exposure [past (*medium confidence*) and projected (*medium confidence*)]. 2) Slowdown of TC forward translation speed over the contiguous USA and subsequent increase in TC rainfall [past (*medium confidence*) and projected (*low confidence* due to lack of studies)]. 3) Increase in mean and maximum SCS rain-rate and increase in springtime SCS frequency and season length over the contiguous USA [past (*low confidence* due to lack of reliable data) and projected (*medium confidence*)]. This figure is adapted from Chapter 11 Figure 11.20.

Compound extreme events are the combination of multiple drivers and/or hazards over space and time that contribute to societal or environmental risk. They can occur on various spatial scales from sub-national to global and can often impact ecosystems and societies more strongly than when such events occur in isolation. Examples are concurrent heatwaves and droughts in multiple locations, compound flooding (e.g., a storm surge in combination with extreme rainfall and/or river flow), compound fire weather conditions (i.e., a combination of hot, dry, and windy conditions), or concurrent extremes at different locations such as in multiple breadbaskets. The chances of experiencing compound extreme events has *likely* increased since the 1950s.

For more information, see the Summary for Policymakers Section A.3, and the Technical Summary Section TS.2.4 and Chapter 9 Box 9.2 (marine heatwaves), the Technical Summary Box TS.4 and Chapter 9 Section 9.6.4 (regional sea level), the Technical Summary Section TS.2.6 and Box TS.6, Chapter 8 Section 8.3.2 and Chapter 11 Section 11.7 (storms), and the Technical Summary Section TS.2.6, Chapter 11 Section 11.8 (compound extremes).

Past Trends do not Appropriately Project Future Changes

Observed and attributed climate change provide a coherent picture of a warming world. However, the emergence of observed and attributable changes across regions, and the unprecedented nature of some of these changes, demonstrate methods using past data to calculate impact and risk may not be as applicable for projecting future risks and impacts. Climatological statistics calculated in the 20th century or early 21st century, such as the return period of a given climate extreme in a given region, may no longer apply, which can alter the risk estimation of future events. Incorporating climate projections rather than past trends into risk analysis can help estimations. However, care needs to be taken to ensure fitness for purpose when using climate model data, and potential biases should be taken into account (See Box: How to use and interpret near-term climate information and Annex.I Data).

For more information see Chapter 10 Section 10.5 and Chapter 12 Section 12.3.

Future Climate Change

Introduction to Scenarios Used in Working Group I to Project Future Climate

The physical climate science community usually agrees on a set of scenarios to be used in coordinated modelling efforts such as the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme. This helps to ensure that climate projection results are comparable when studies by different research groups, possibly using different climate models, are published.

Throughout the Working Group I Sixth Assessment Report, five illustrative scenarios from the scientific literature are used to explore the climate response to a broad range of greenhouse gas, land-use and air pollutant futures. This set of scenarios is used to drive climate model projections of changes in the climate system. The scenarios are based on a combination of information on socio-economic development and the resulting climate development. They are referred to as SSPx-y scenarios, where 'SSPx' refers to a specific Shared Socio-economic Pathway (SSP) describing the socio-economic trends and assumptions underlying the scenario, and 'y' refers to the approximate change in Earth's energy balance by 2100 for a given scenario, described as the radiative forcing (measured in W/m^2). Note there are many more SSPs beyond the five used in Working Group I.

Scenario SSP1-1.9 represents the low end of future carbon dioxide and other greenhouse gas emissions pathways considered in the Working Group I Sixth Assessment Report, with a good chance of limiting warming to below 1.5°C in 2100, with a limited overshoot/exceedance of that warming level over the course of the 21st century. At the opposite end, scenario SSP5-8.5 represents the highest future carbon dioxide and other greenhouse gas emissions pathways from the literature, resulting in much higher levels of warming, around 4.4°C by 2100. Scenarios SSP2-4.5 and SSP1-2.6 represent pathways with stronger climate change mitigation and thus lower carbon dioxide and other greenhouse gas emissions. Scenario SSP1-2.6 limits warming to below 2°C. Projections using the scenario SSP3-7.0, corresponds to a situation where carbon dioxide emissions remain close to today's levels for several decades before slowly declining, resulting in around 3.6°C warming by 2100. Scenario SSP3-7.0 has overall lower carbon dioxide and other greenhouse gas emissions than SSP5-8.5, but carbon dioxide emissions still almost double by 2100 compared to today's levels. Figure 5 shows the evolution of carbon dioxide emissions over the 21st century across the five SSPs considered here and the effect this has on global surface temperature projected using climate models.

In summary, emissions vary between scenarios depending on socio-economic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, levels of air pollution control. Alternative assumptions may result in similar emissions and climate responses, but the socio-economic assumptions and the feasibility or likelihood of individual scenarios are not part of the WGI assessment. For example, the plausibility of the high emissions levels underlying scenarios (such as RCP8.5 or SSP5-8.5) has been debated in the scientific literature, as well as in current climate policies, in light of recent developments in the energy sector. The feasibility of scenarios, for example, in relation to current trends, are informed by the Working Group III contribution to the IPCC Sixth Assessment Report.

For more information see the Technical Summary Cross-Section Box TS.1, Chapter 1 Section 1.6, and Chapter 4 Section 4.3.

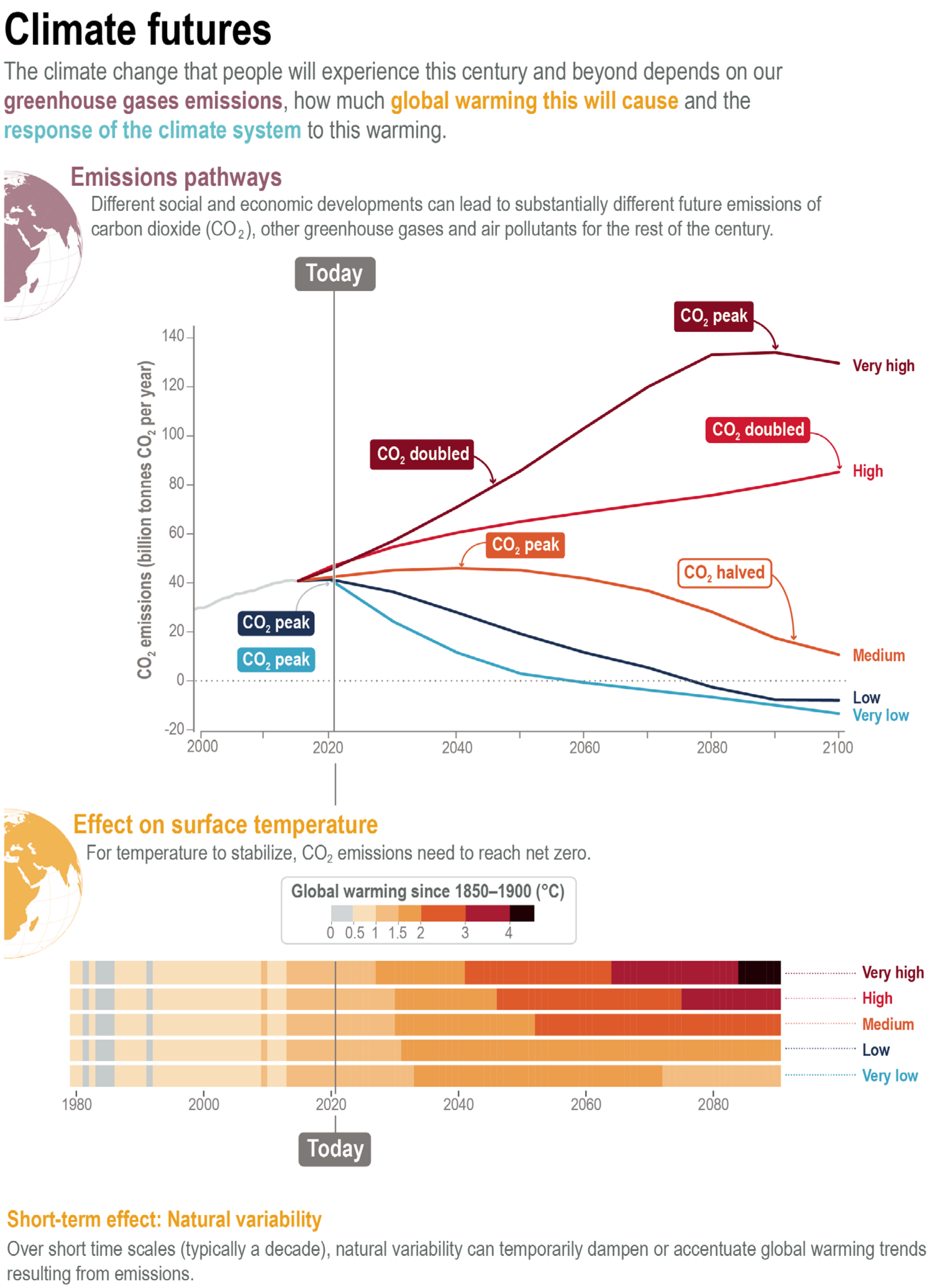


Figure 5: Linking carbon dioxide emissions, global warming and effects on the climate systems. (top) Annual emissions of carbon dioxide for the five core Shared Socio-economic Pathway (SSP)

scenarios (very low: SSP1-1.9, low: SSP1-2.6, medium: SSP2-4.5, high: SSP3-7.0, very high SSP5-8.5). (bottom) Projected warming for each of these emissions scenarios. This figure is sourced from the Technical Summary Infographic.

How to Compare Shared Socio-economic Pathways (SSPs) and Representative Concentration Pathways (RCPs)

The Shared Socio-economic Pathways (SSPs) are related to the Representative Concentration Pathways (RCPs) that were used in the IPCC Fifth Assessment Report, but they are not directly comparable. Both scenario sets are categorized similarly in terms of the resulting climate development considered, that is, by reference to the approximate radiative forcing levels at the end of the 21st century. So, the '8.5' in the SSP5-8.5 scenario and the '8.5' in the RCP8.5 scenario both stand for an approximate radiative forcing level of 8.5 W m^{-2} in 2100. However, the composition of different gases between corresponding SSPs and RCPs differ; for example, the SSP5-8.5 scenario has higher carbon dioxide concentrations but lower methane concentrations than RCP8.5. Furthermore, the trajectories of emissions over the 21st century may differ, even if they result in the same radiative forcing by 2100. And, finally, the overall radiative forcing may differ – in fact, it tends to be higher for SSP scenarios compared to RCP scenarios. Overall, the differences in climate projections arising from corresponding SSPs and RCPs are partially due to different scenario characteristics rather than solely due to the different climate model characteristics.

For more information see the Summary for Policymakers Box SPM.1, the Technical Summary TS.1.3, Chapter 1 Section 1.6.1 and Cross-Chapter Box 1.4, Chapter 4 Section 4.6.2 and Chapter Atlas Section 1.4.3.

Projected Temperature Changes are Based on Multiple Lines of Evidence

Rather than solely using raw climate model output to project global temperatures, the Working Group I Sixth Assessment Report combines climate model data with other lines of evidence (such as historical data and observations) to constrain future projections. The result is a smaller *likely* range of future temperature changes across the five illustrative scenarios. How to access this constrained temperature assessment data is discussed in Annex.I Data.

For more information see the Technical Summary Cross-Section Box TS.1 and Chapter 4 Section 4.3.

Translating Scenarios Across Global Warming Levels

For many climate variables, scenario information can be presented across specific global warming levels, such as 1.5°C, 2°C, or 4°C above pre-industrial levels. This is because many climate characteristics (e.g., rainfall, heatwaves or droughts) scale almost linearly with the level of global warming. Robust projected geographical patterns of many variables can be identified at a given level of global warming, common to all scenarios considered and independent of the timing when a given global warming level is reached (see Section Future global climate changes). For some climate changes however, such as sea level rise, scenario information is best presented temporally, to fully capture how these slower, less linear changes evolve over time.

For more information see Chapter 11 Cross-Chapter Box 11.1 and Chapter Atlas Section 1.3.

Projections Show Similar Changes in the Coming Couple of Decades

The expectation that all emissions can stop from one day to the next is unrealistic and so, the five illustrative scenarios considered in the report assume different levels of mitigation that are implemented across different time frames throughout the 21st century. Due to the time commitment needed to implement mitigation actions, warming in the near term[4] continues, even in the scenarios that feature strong reductions in greenhouse gases and air pollutants. In fact, all five scenarios lead to similar warming until the 2050s (Table 2). Averaged over the near term, global surface temperature is projected to reach 1.5°C relative to 1850-1900, noting that global temperature has already increased by 1.09°C. However, if greenhouse gas emissions are strongly reduced over the coming decades (such as in scenario SSP1-1.9), the warming would remain close to 1.5°C, whereas in all other scenarios it continues to increase over the century. SSP1-2.6 manages to limit warming below 2°C, while all other scenarios fail to meet the Paris Agreement goal of holding warming well below 2°C while pursuing a limit of 1.5°C (Table 2).

For more information see the Summary for Policymakers Sections B.1 and B.5, the Technical Summary Cross-Section Box TS.1 and Chapter 1 Section 1.4.1.

Crossing 1.5°C Global Warming is Close

Global warming levels of 1.5°C and 2°C will be exceeded unless deep reductions in carbon dioxide and other greenhouse gas emissions occur in the coming years and continue for decades. In all cases, our best estimate is that global surface temperature, averaged over

4 Defined as 2021-2040

a 20-year period, will reach 1.5°C during 2021-2040. Exceeding 2°C global warming is only avoided in the two scenarios with the most stringent mitigation (Table 2).

Table 2: Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five scenarios considered in the report. Temperature differences (°C) are relative to the pre-industrial baseline period 1850–1900. Bracketed numbers indicate the assessed *very likely* range. This table is sourced from the Summary for Policymakers Table SPM.1. See Box: How to use and interpret near-term climate information for more information on why 20-year averages are presented.

	Projected global warming level (°C) at specific 20 year timeframe		
	Near term, 2021–2040	**Mid-term, 2041–2060**	**Long term, 2081–2100**
SSP1-1.9	1.5 (1.2-1.7)	1.6 (1.2-2.0)	1.4 (1.0-1.8)
SSP1-2.6	1.5 (1.2-1.8)	1.7 (1.3-2.2)	1.8 (1.3-2.4)
SSP2-4.5	1.5 (1.2-1.8)	2.0 (1.6-2.5)	2.7 (2.1-3.5)
SSP3-7.0	1.5 (1.2-1.8)	2.1 (1.7-2.6)	3.6 (2.8-4.6)
SSP5-8.5	1.6 (1.3-1.9)	2.4 (1.9-3.0)	4.4 (3.3-5.7)

For more information see the Summary for Policymakers Section B.1 and the Technical Summary Cross-Section Box TS.1.

The World Will Experience Occasional Years of 1.5°C Global Warming Before Reaching a Climatological Mean of 1.5°C Global Warming

The projections reported in the IPCC Working Group 1 Report are values for 20-year global average temperature increase, which is how global warming is defined in the Report. However, the global average temperature in any given year can be slightly higher or lower than this long term trend because of year-to-year variations that may be unrelated to global warming (*see the Box: How to use and interpret near-term climate information*). These year-to-year variations imply that even if the global average temperature increase in a given year reaches 1.5°C for the first time, this does not mean the planet is already experiencing 1.5°C of global warming. The latter will only occur once the global average temperature increase over multiple decades is at 1.5°C. By the 2030s, each year has an approximately 50% chance of having an annual global surface temperature of 1.5°C above the pre-industrial level.

For more information see the Technical Summary Cross-Section Box TS.1 and Chapter 4 Section 4.3.

How to use and Interpret Near-Term Climate Information

Relevant Time Horizons for Actuaries

The relevant projection horizon varies depending on the actuarial assignment. When underwriting short-term commercial risks, actuaries need only to project for the duration of the risk insured, hence the projection is usually short, from 3 to 5 years. When making strategic projections to assess the viability of an institution over the long run, a longer projection would be needed. For example, an institution may worry about the affordability of its products over the next 20 years or so and assess its ability to influence building codes and land use in order to protect its clients and its client base. With regard to banks and other lenders, an assessment of the likelihood of loan defaults over 30-year periods is often required. Projections of social security commitments by actuaries on behalf of governments would be longer (50 years and maybe more) to assess intergenerational subsidies and long term sustainability.

How to use and Interpret Near-Term Climate Information

Planning for the full range of possible changes requires taking into account natural climate variability and human-caused change. Natural variability refers to variations in climate that are caused by drivers other than humans. It includes variability that is **internally** generated within the climate system and variability that is driven by natural **external** factors. Natural variability is a major cause of year-to-year changes in global climate and can play a prominent role in trends over multiple years or even decades. **Internal** natural variability includes so-called modes of variability such as an equatorial Pacific phenomenon called the El Niño–Southern Oscillation (ENSO), which occurs every 2 to 7 years and can (among other things) increase or decrease the chances of wildfires, droughts and severe precipitation in many regions of the world for several months; or the Atlantic Multi-decadal Variability, which can increase or decrease (among other things) the amount of rainfall in regions around the Atlantic Ocean for several decades. An example of **external** natural variability (outside of the climate system) is a large volcanic eruption, which could actually cool the Earth's temperature by about 0.5°C to 1°C for a few years.

The effects of internal variability are usually larger at the regional scale and average out at increasingly larger scales, and they are larger for variables such as rainfall and wind, and smaller for temperature. This is important to consider when preparing for future climate changes. In particular, at the regional scale, trends can be strongly altered by internal variability as well as anthropogenic forcings. Thus, regional changes for the coming decades can deviate from the projected trend, resulting in slightly smaller or larger changes and the implications of those changes may be smaller or larger. Large single-model ensembles (see glossary definition Climate simulation ensemble) are now available and provide a more comprehensive spectrum of possible changes associated with internal variability.

Reference periods of 20 years are considered long enough to show future changes in many climate variables when averaging over outputs of multiple computer models, and short enough to show the evolution of changes throughout the 21st century.

For more information see the Technical Summary Table TS.4, Chapter 4 Section 4.5.3 (projected changes of modes of variability), Chapter 8 Section 8.4.2.9 (consequences for water cycle changes) and Chapter 10 Sections 10.3 and 10.4 (considerations when constructing regional climate information).

Future Global Climate Changes

Many changes in the climate system become larger in direct relation to increasing global warming. They include changes to mean climate, increases in the intensity and variability of the water cycle, and increases in the frequency and intensity of many extremes.

With every additional increment of global warming, the pattern of observed change intensifies in every region (Figure 6). For temperature, it is *virtually certain* that changes will continue to be amplified over land and in the Arctic, compared to the global average (panels a+b). With every increment of global warming, annual mean precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and some areas in the tropics (panels c) (*high confidence*).

Changes in precipitation lead to changes in soil moisture. Together with the fact that a warmer atmosphere enhances evaporation and plant transpiration, this further reduces soil moisture (panels d). Soil moisture is projected to decrease with every increment of global warming in semi-arid areas dominated by winter rainfall (*high confidence*).

Continued global warming is projected to further intensify the global water cycle, its variability, global monsoon precipitation and the severity of wet and dry events. Precipitation and surface water flows are projected to become more variable over most land regions within seasons and from year to year (*high confidence*).

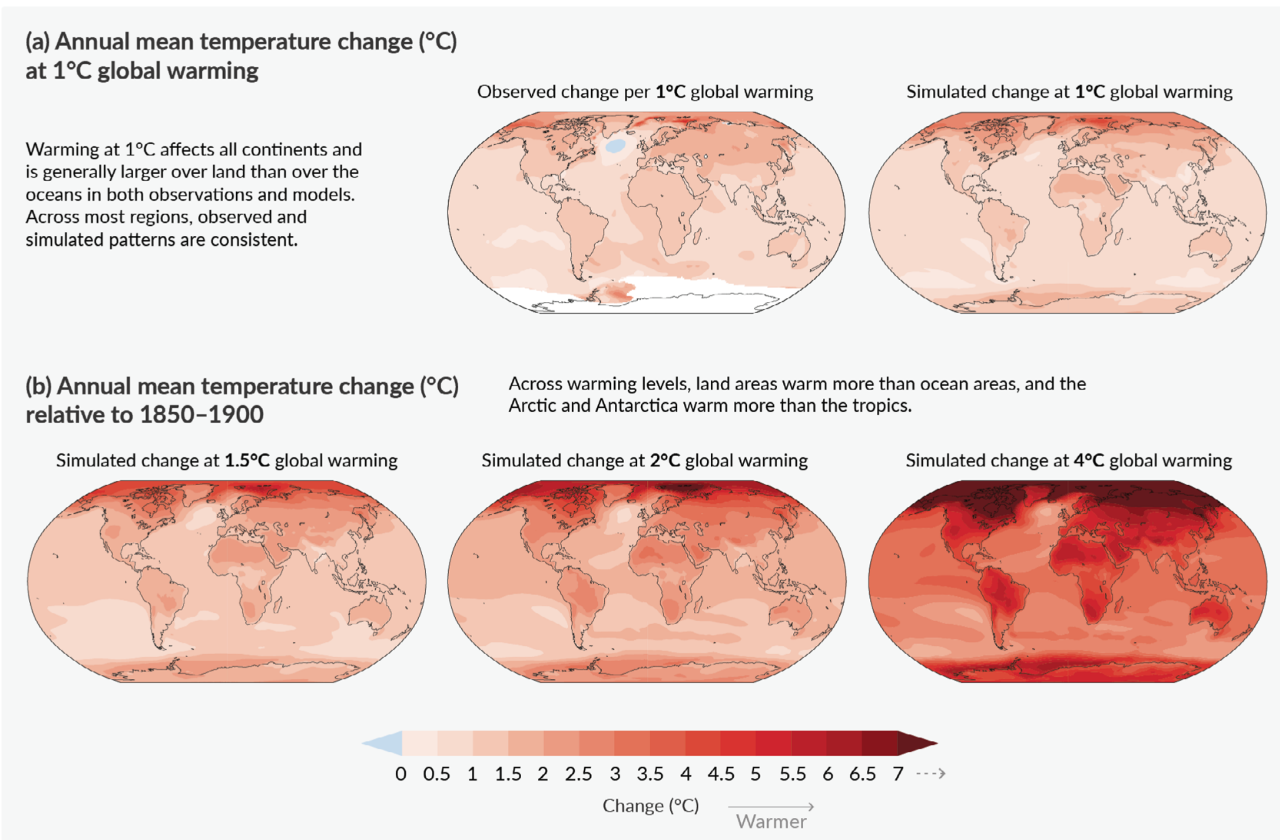
Precipitation variability within a year will increase with global warming (*medium confidence*). Seasonal variability in precipitation will increase faster than the mean seasonal precipitation (*high confidence*). As warming increases, increasing areas of land will experience either increases or decreases in precipitation (*medium confidence*) and, on average, very wet seasons will become even wetter and very dry seasons more intense (*high confidence*).

Additional warming is projected to further amplify permafrost thawing and the loss of both seasonal snow cover and Arctic sea ice (Figure 7). The earlier onset of spring snowmelt will lead to higher peak river flows and reduced summer river flows in snow-dominated regions. The volume of perennially frozen soil within the upper 3 m of the ground will decrease by about 25% per 1°C of global surface air temperature change. The Arctic is *likely* to be practically free of sea ice in September at least once before 2050 under the five scenarios that were considered, with more frequent occurrences for higher warming levels. Upper ocean

acidification and loss of oxygen in the ocean will continue to worsen in the 21st century, at rates dependent on future emissions.

For more information see the Summary for Policymakers Section B.2, B.3 and B.5, the Technical Summary Box TS.2, and, for specific topics, the Technical Summary Boxes TS.6 (water cycle) and Box TS.13 (monsoon), Section TS.2.5 (cryosphere), and Chapter 4 Sections 4.5.1 and 4.6.1 and Chapter 8 Section 8.4.1 (variability).

With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture



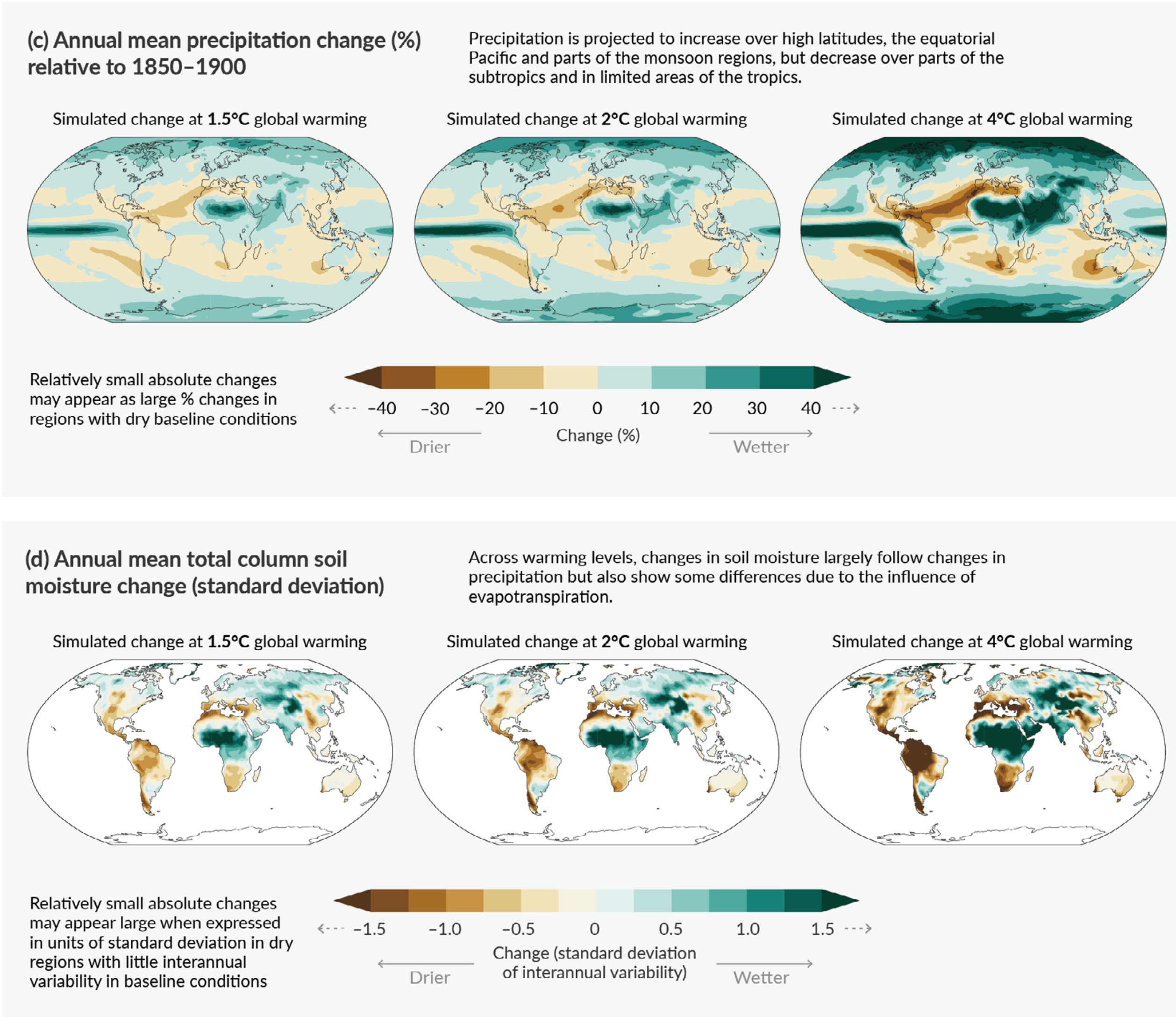


Figure 6: With every increment of global warming, changes in regional mean temperature, precipitation and soil moisture get larger. Panel a): The left map shows the observed changes in annual mean surface temperature anomalies linearly regressed against global surface temperature in the period 1850–2020 (°C per °C of global warming). Observed temperature data are from Berkeley Earth. White indicates areas where time coverage was 100 years or less and thereby too short to calculate a reliable linear regression. The right map shows simulated annual mean temperature at a global warming level of 1°C relative to 1850–1900. Simulated annual mean (Panel b) temperature (°C), (Panel c) precipitation (%) and (Panel d) soil moisture (standard deviation of interannual variability 1850-1900) at global warming levels of 1.5°C, 2°C and 4°C relative to 1850–1900. In panel (d), the unit is the standard deviation of interannual variability in soil moisture during 1850–1900, a widely used metric in characterizing drought severity. Simulated changes correspond to CMIP6 multi-model mean change (median change for soil moisture) at the corresponding global warming level (20-yr mean global surface temperature change relative to 1850–1900). Results from all models reaching the corresponding warming level in any of the five core scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) are averaged. The triangles at each end of the colour bar indicate values above or below the given limits. This figure is sourced from the Summary for Policymakers Figure SPM.5. See the Atlas Cross-Chapter Box Atlas.1 for displaying robustness in maps.

Extremes Scale With Global Warming but Natural Variability Will Modify Changes Over Shorter Timeframes, Particularly Evident at Regional Scales

Every additional 0.5°C of global warming causes discernible increases in the intensity and frequency of hot extremes, including heatwaves, and heavy precipitation as well as agricultural and ecological droughts in some regions. The changes in frequency and intensity are illustrated in Figure 7 for events that occurred once in 10 years on average in a climate without human influence. Compared to pre-industrial levels, experiencing a 1-in-10 year heatwave event is already now more than 2.5 times as likely, but this increases to more than 4 times as likely at 2°C. Similarly, a 1-in-10 year heavy precipitation event in 1850-1900 is now 1.3 times as likely, and will be 1.7 times as likely at a global warming of 2°C (and 7% more per °C for their intensity). Note here that heavy precipitation alone may not translate to increases in flood risk, as this depends on local factors (see FAQ 8.2 and the Working Group II report for more information). Agricultural and ecological drought events of a given severity are now more than 1.5 times as likely and will be almost 2.5 times as likely at 2°C global warming.

Note that by defining extremes as threshold exceedances, changes in intensity and frequency of extremes are linked. For instance, if rainfall intensities increase in a future climate, the future probability that the threshold defining a 10-year event is exceeded gets higher (top row in figure 7), but equally, a 10-year event in a future climate would correspond to a higher threshold (bottom row in figure 7). Thus, the statements in the top and bottom row of figure 7 are equivalent, but just looking at extremes from two perspectives.

Cities intensify human-caused warming locally, and further urbanization together with more frequent hot extremes will increase the severity of heatwaves (*very high confidence*). Urbanization also increases mean and heavy precipitation over and/or downwind of cities (*medium confidence*) and resulting runoff intensity (*high confidence*). In coastal cities, the combination of more frequent extreme sea level events (due to sea level rise and storm surge) and extreme rainfall/riverflow events will make flooding more probable (*high confidence*).

For more information see the Summary for Policymakers Sections B.2 and C.2, the Technical Summary Box TS.10 and Box TS.14.

Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming

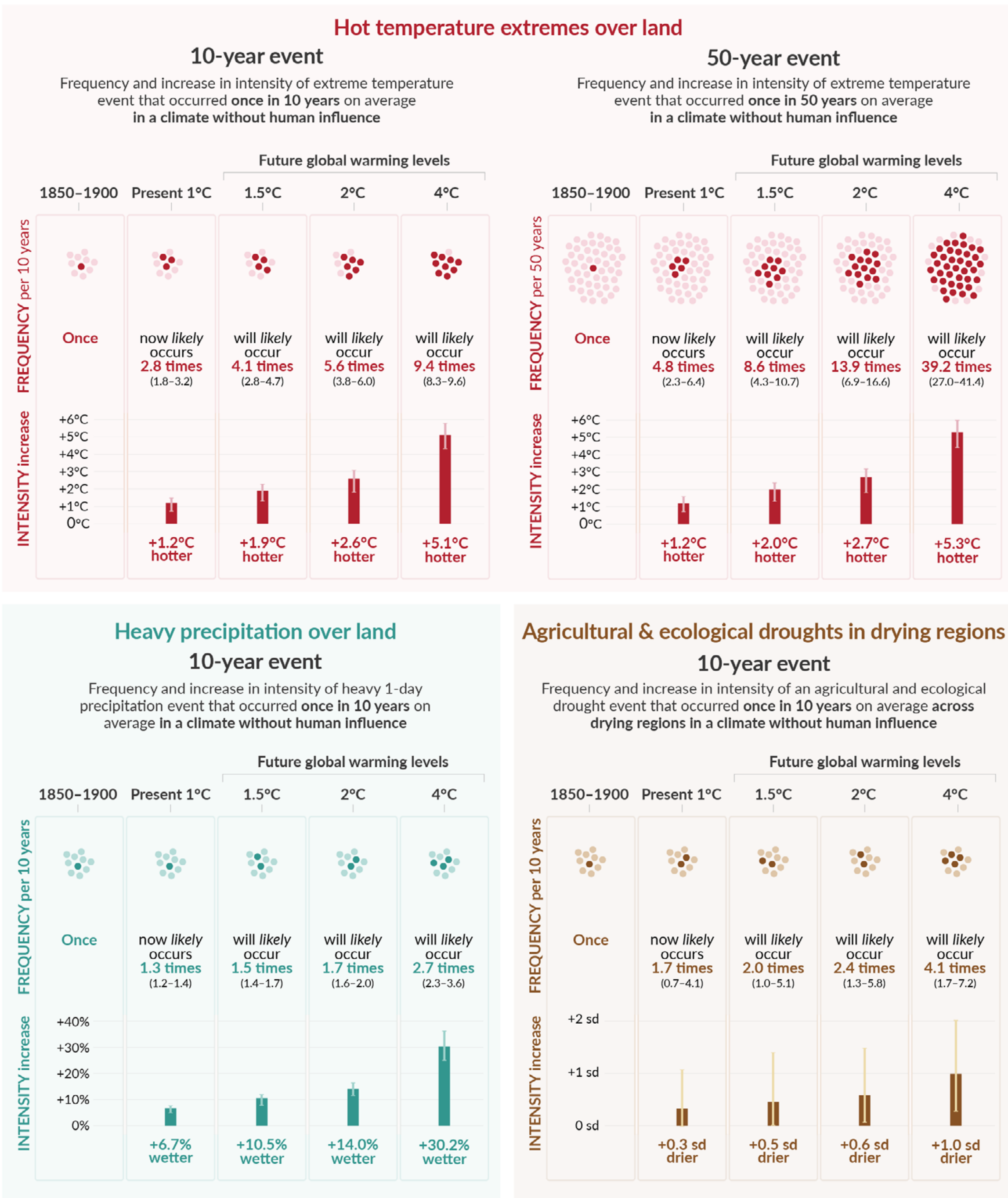


Figure 7: Projected changes in frequency and intensity of extremes are larger for every additional increment of global warming. Projected changes in the intensity and frequency of extreme temperature, extreme precipitation and droughts for global warming levels of 1°C, 1.5°C, 2°C, and 4°C, relative to their respective 1850–1900 reference period. Extreme temperature events are defined as the daily

maximum temperatures that were exceeded on average once in a decade (10-year event) or once in 50 years (50-year event) during the 1851–1900 reference period. Extreme precipitation events are defined as the daily precipitation amount that was exceeded on average once in a decade during the 1850–1900 reference period. Agricultural and ecological drought events are defined as the annual average of total column soil moisture that was below its 10th percentile during the 1850–1900 base period. For extreme temperature and extreme precipitation, results are shown for the global land. For drought, results are shown for the AR6 regions in which there is at least medium confidence in a projected increase in agriculture/ecological drought at the 2°C warming level compared to the 1850–1900 base period. The dots and bars show the medians and their respective very likely ranges based on the multi-model ensemble from simulations of CMIP6 under different SSP scenarios. Dark dots indicate years in which the extreme threshold is exceeded. Light dots are years when the threshold is not exceeded. Changes in the intensity of drought are expressed as fractions of standard deviation of annual soil moisture. This figure is sourced from the Summary for Policymakers Figure SPM.6.

Figure 8 shows projected changes for the near-term (2021-2040) for selected indices relevant for risk: a) days with maximum temperature above 35ºC, b) total precipitation c) maximum 5-day precipitation, and d) consecutive dry days compared to the modern-day baseline (1995-2014). Near-term projections often display lower model agreement (shown by diagonal lines) compared to mid- or long-term projections due to the relatively greater role of natural variability across shorter time frames. The metrics shown in figure 8 are selected because they relate closely to insurance losses connected to flooding and agricultural production.

For more information see the Interactive Atlas: https://interactive-atlas.ipcc.ch/, Chapter 1 Section 1.4.1 (reference periods) and the Atlas Cross-Chapter Box Atlas.1 (displaying robustness in maps).

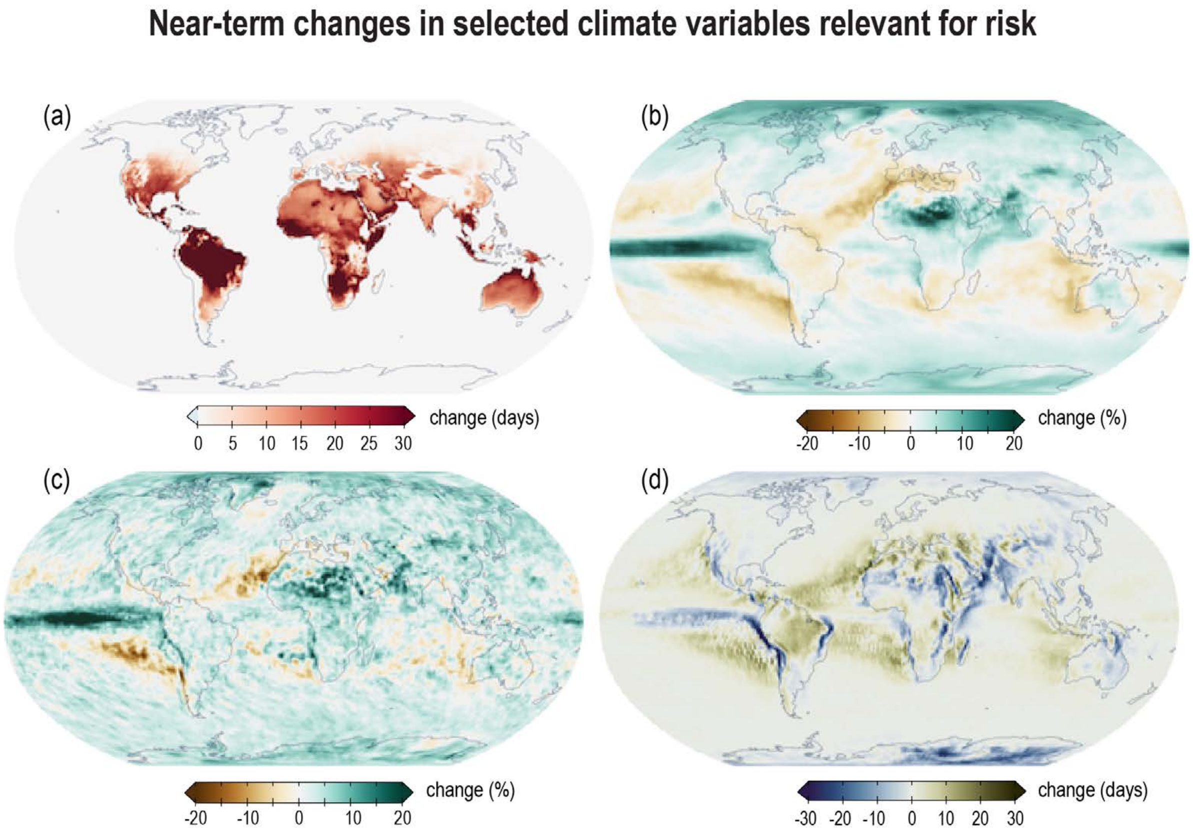


Figure 8: Projected changes using CMIP6 model output for SSP3-7.0 for the near-term (2021-2040) compared to the modern-day reference period (1995-2014) for (a) days with (bias adjusted) maximum temperature above 35°C (number of days change) (b) total precipitation (% change) (c) maximum 5-day precipitation (% change), and (d) consecutive dry days (number of days change). This figure is sourced from the Interactive Atlas: https://interactive-atlas.ipcc.ch/regional-information. See the Atlas Cross-Chapter Box Atlas.1 for displaying robustness in maps.

Some Long-Term Climate Changes Cannot be Avoided, but Their Rates can be Slowed with Aggressive Mitigation

Some components of the climate system respond very slowly to emission changes. As such, our past emissions have *already* committed the climate system to some further changes over time frames of decades, centuries and even millennia. Sea level rise and ice sheet retreat are examples of very slow-responding changes. Figure 9 shows projected changes across the five illustrative scenarios for a number of climate components, including sea level rise. Shading in the panels represent the assessed *likely* or *very likely* ranges.

For more information see the Summary for Policymakers Section B.5 and the Technical Summary Box TS.4.

Human activities affect all the major climate system components, with some responding over decades and others over centuries

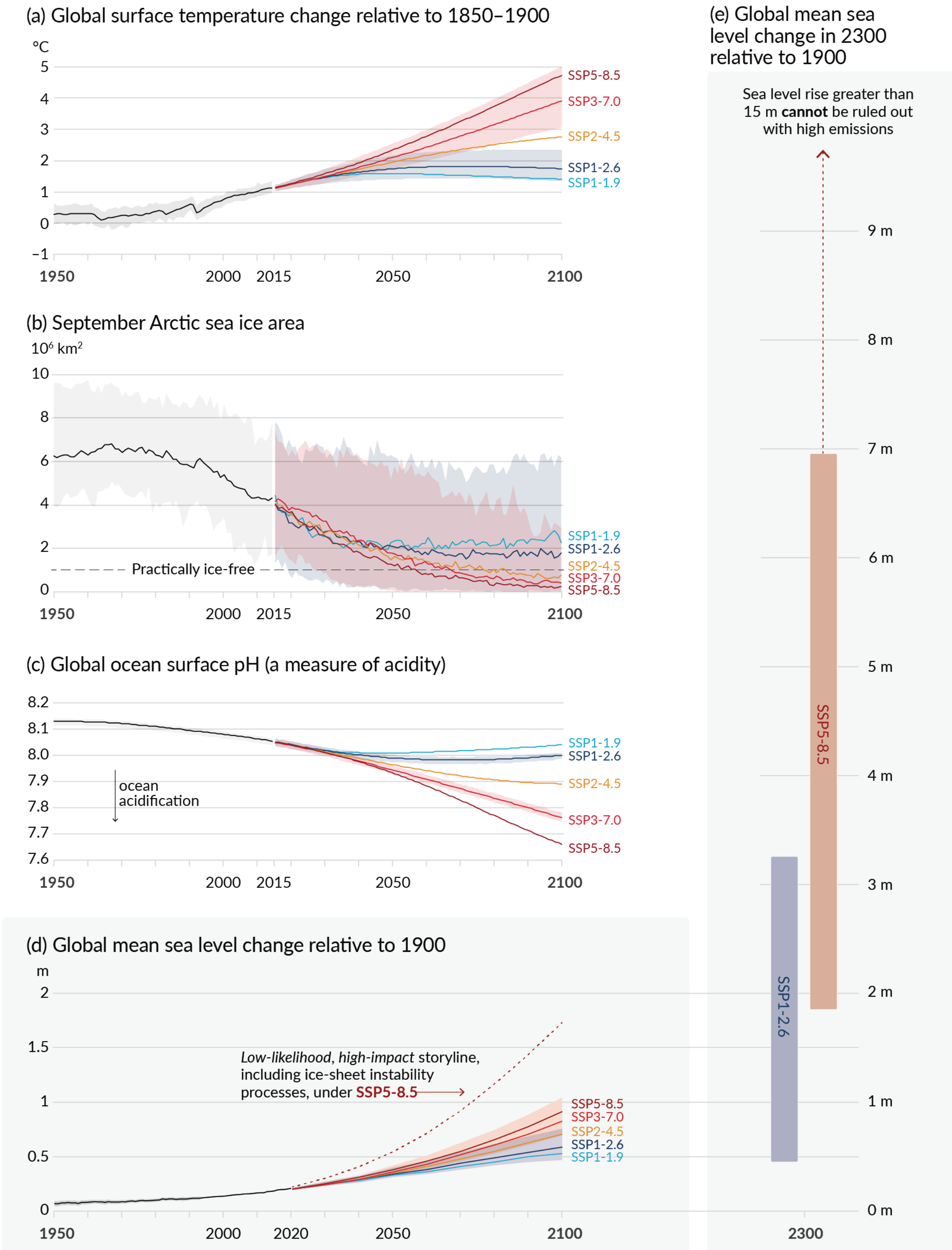


Figure 9: Selected indicators of global climate change under five illustrative scenarios. Panel (a) Historical and future assessed global surface temperature changes relative to 1850-1900. Panel (b) September Arctic sea ice area based on CMIP6 models. Panel (c) Global surface pH, a measure of acidity, based on CMIP6 models. Panel (d) Global mean sea level changes from 1950–2100 relative to 1900. The dashed line shows a likely upper limit if low confidence processes (primarily Marine Ice Cliff Instability) are included in the assessment. Panel (e) Global mean sea level changes by 2300 relative to 1900 (only SSP1-2.6 and SSP5-8.5 are projected at 2300 due to limited modelling for other scenarios beyond 2100). Shadings in all panels show selected very likely ranges, except panels (d) and (e) which show assessed likely ranges. This figure is sourced from the Summary for Policymakers Figure SPM.8.

By 2050, global average **sea level** will rise by 15-30 cm (6-12 inches) above the present-day level, almost independently of how quickly global greenhouse gas emissions are reduced. Sea level rise is not uniform on a global scale: some areas will see much higher sea level rise and others may see a decline (see Section Future regional climate changes). By 2050, the report estimates that extreme sea level events that occurred once per century in the recent past will occur globally 20 to 30 times more frequently. They will occur annually or even more frequently at 19–31% of tide gauge locations. Beyond 2050, sea level will continue to rise, but with a rate and magnitude strongly dependent on choices regarding future greenhouse gas emissions. By 2100, once-per-century extreme sea level events will occur approximately 160 times more frequently (if warming is limited to 2°C) and would occur at least annually at 60% of these locations. If warming reaches around 4.5°C, these events would become approximately 530 times more frequent and occur at least annually at 80% of the tide gauge locations. (*medium confidence*)

For more information see Technical Summary Box TS.4 and Chapter 9 Section 9.6.4.

Sea levels will continue to rise for thousands of years even after global temperatures are stabilized, due to the very slow response time of ice sheets and the deep ocean to increasing global warming. Even if temperatures are limited to 1.5°C global warming, 2 m (~79 inches) of sea level rise would be committed over 2000 years and 6m (~236 inches) sea level rise would be committed over 10,000 years. Therefore, it is not a matter of if global mean sea level rise will reach 1m or even 2 m (about 39 or 79 inches, respectively), it is a matter of when. The rate of sea level rise is slower in scenarios with high levels of mitigation. For example, global average sea level would exceed 1m (about 39 inches) early in the next century for warming of 4°C, but would not do so until the 23rd century if warming is limited to below 2°C (timing of 1 m / 39 inches for SSP1-1.9: median 2275, *likely* range of 2177 to post 2300, compared to SSP5-8.5: median 2122, *likely* range 2099-2148).

For more information see the Technical Summary Box TS.4, Figure 1c and the Technical Summary Infographic.

Climate Changes Outside of the *Very Likely* Range Cannot be Ruled out

Low-likelihood outcomes cannot be ruled out and should be part of risk assessment. Examples include ice-sheet collapse, abrupt ocean circulation changes, some compound extreme events, and larger warming than the assessed *very likely* range. If warming is higher than expected, global and regional changes in many aspects of the climate system, such as regional precipitation and other climatic impact-drivers (see Section Climate drivers related to risk and impact), would also exceed their assessed *very likely* ranges (*high confidence*). The probability of low-likelihood, high impact outcomes increases for higher global warming levels (*high confidence*).

For this reason, Figure 9 panel (e) on sea level rise includes a low-likelihood, high end storyline sea level storyline that assumes faster-than-projected disintegration of marine ie shelves and abrupt onset of ice sheet instability in Antarctica (and faster than projected changes in mass loss from Greenland) to account for deep uncertainty on the timing of the possible onset of such processes and potential to accelerate sea level rise.

Some low-likelihood, high-impact outcomes could still occur even within the *very likely* warming ranges. Abrupt responses and tipping points of the climate system, such as strongly increased Antarctic ice-sheet melt and forest dieback, cannot be ruled out (*high confidence*).

For more information see the Summary for Policymakers Section C.3, the Technical Summary Box TS.4 and Chapter 4 Table 4.10.

Future Air Quality Levels are Primarily Driven by Changes in Precursor Emissions as Opposed to Climate Change

Future air quality – in terms of surface ozone and particulate matter concentrations – is assessed for the five illustrative SSP scenarios. For aerosols and non-methane ozone precursors (emissions that cause change to air quality by reacting with other species in the atmosphere), the emissions vary between scenarios as a result of different socio-economic assumptions, different levels of climate change mitigation, and different assumptions about air pollution controls. Considering climate and emissions changes in the future, air pollution projections range from strong reductions in global surface ozone and fine particulate matter (in scenarios with strong mitigation of both air pollution and climate change) to no improvement and even deterioration (e.g., a scenario without climate change mitigation and with only weak air pollution control).

Future climate change is projected to have mixed effects, positive or negative, on ozone and particulate matter. A warmer climate is expected to reduce surface ozone in regions remote from pollution sources but is expected to increase it over polluted regions, depending on ozone precursor levels. It is expected to have an overall low effect on global surface particulate matter, but stronger effects are not excluded in regions prone to specific meteorological conditions. Overall, there is low confidence in the response of surface ozone and particulate matter to future climate change due to the uncertainty in the response of the natural processes to climate change.

For more information see the Summary for Policymakers Section D.2, the Technical Summary Box TS.7, and Chapter 6.

Future Regional Climate Changes

What Does the IPCC WGI Mean by 'Regions'?

Although climate change is a global phenomenon, its manifestations and consequences are different in different regions, and therefore climate information on spatial scales ranging from sub-continental to local is used for impact and risk assessments. The term region may refer to a large area such as a monsoon region, but may also be confined to smaller areas such as coastlines, mountain ranges or human settlements like cities. Users such as actuaries and natural catastrophe modellers may need climate information for these ranges of scales since their operating and adaptation decision scales may depend upon the context.

For more information see Chapter 1, Section 1.4.5, and Chapter 10, Section 10.1.1.

Spatially aggregated regional information across the report is provided for different **predefined regional sets:**

- The sub-continental Working Group I Sixth Assessment Report land and ocean reference regions
- Working Group II Sixth Assessment Report regions based around continents
- Typological regions, including:
    - Monsoon regions
    - Major river basins
    - Small-island regions
    - Ocean biological activity regions

The Working Group I Sixth Assessment Report Interactive Atlas (https://interactive-atlas.ipcc.ch/), an online tool that supports the assessment results of the Working Group I Chapters, contains climate information across all regions described above. Figure 10 shows the sub-continental reference land and ocean regions used in the Working Group I assessment. See the Annex.1 Data of this summary for more information.

For more information see the Technical Summary Section TS.4 and the Atlas Chapter Section Atlas.1.3.

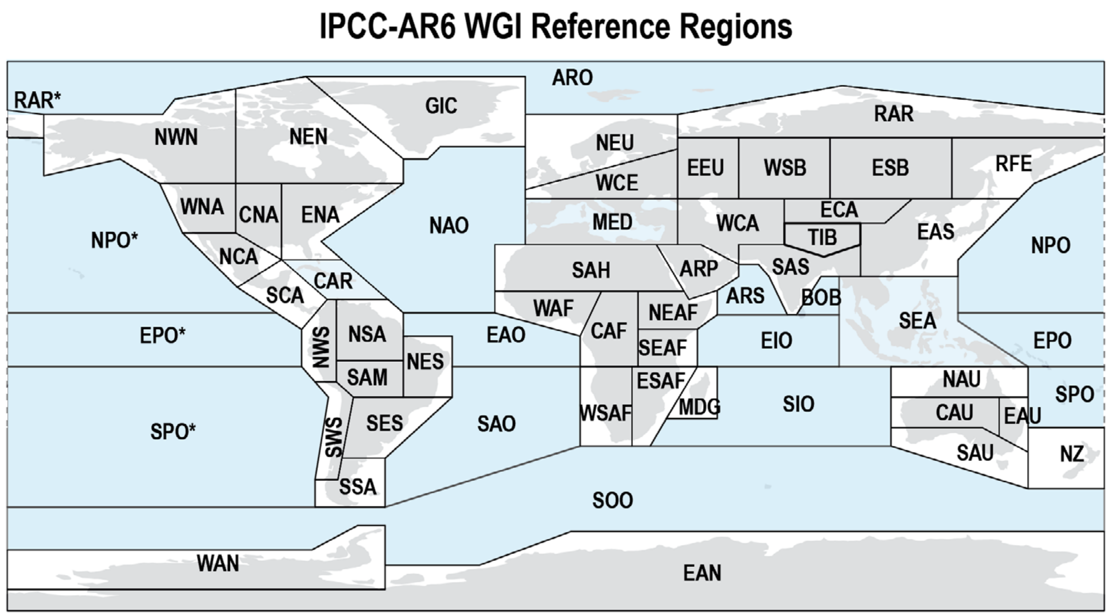


Figure 10: The Working Group I Sixth Assessment Report subcontinental reference regions. Acronyms correspond to: **North America**: NWN (North-Western North America, NEN (North-Eastern North America), WNA (Western North America), CNA (Central North America), ENA (Eastern North America), **Central America**: NCA (Northern Central America), SCA (Southern Central America), CAR (Caribbean), **South America**: NWS (North-Western South America), NSA (Northern South America), NES (North-Eastern South America), SAM (South American Monsoon), SWS (South-Western South America), SES (South-Eastern South America), SSA (Southern South America), **Europe**: GIC (Greenland/Iceland), NEU (Northern Europe), WCE (Western and Central Europe), EEU (Eastern Europe), MED (Mediterranean), **Africa**: MED (Mediterranean), SAH (Sahara), WAF (Western Africa), CAF (Central Africa), NEAF (North Eastern Africa), SEAF (South Eastern Africa), WSAF (West Southern Africa), ESAF (East Southern Africa), MDG (Madagascar), **Asia**: RAR (Russian Arctic), WSB (West Siberia), ESB (East Siberia), RFE (Russian Far East), WCA (West Central Asia), ECA (East Central Asia), TIB (Tibetan Plateau), EAS (East Asia), ARP (Arabian Peninsula), SAS (South Asia), SEA (South East Asia), **Australasia**: NAU (Northern Australia), CAU (Central Australia), EAU (Eastern Australia), SAU (Southern Australia), NZ (New Zealand), **Small Islands**: CAR (Caribbean), PAC (Pacific Small Islands). **Ocean**: ARO (Arctic Ocean), SPO (South Pacific Ocean), EPO (Equatorial Pacific Ocean), NPO (North Pacific Ocean), SAO (South Atlantic Ocean), EAO (Equatorial Atlantic Ocean), NAO (North Atlantic Ocean), EIO (Equatorial Indian Ocean), SIO (South Indian Ocean), ARS (Arabian Sea), BOB (Bay of Bengal), SOO (Southern Ocean). This figure is adapted from the Atlas Chapter Figure Atlas.2.

Climate Drivers Related to Risk and Impact

The climatic impact-driver (CID) framework developed in AR6 supports an assessment of changing climate conditions that are relevant for sectoral impacts and risk assessment. CIDs are physical climate system conditions (e.g., means, extremes, events) that affect an element of society or ecosystems and are thus a potential priority for providing climate information.

Table 3 presents the comprehensive regional CID assessment results from the Working Group I Sixth Assessment Report. The table shows how CIDs are projected to change (increase or

decrease) by 2050, assuming around 2°C of global warming. Future changes to CIDs for land and coastal regions are organized into the following six categories:

- **Heat and cold**: mean air temperature; extreme heat; cold spell; and frost.
- **Wet and dry**: mean precipitation; river flood; heavy precipitation and pluvial flood; landslide; aridity; hydrological drought; agricultural and ecological drought; and fire weather.
- **Wind**: mean wind speed; severe wind storm; tropical cyclones; and sand and dust storm.
- **Snow and ice**: snow, glacier and ice sheet; permafrost; land and sea ice; heavy snowfall and ice storm; hail; and snow avalanche.
- **Coastal**: relative sea level; coastal flood; coastal erosion; marine heatwave; and ocean acidity.
- **Other**: air pollution weather, atmospheric carbon dioxide at surface, and radiation at surface.

Climate change has already altered CID profiles and resulted in shifts in the magnitude, frequency, duration, seasonality and spatial extent of associated indices (*high confidence*). Depending on system tolerance, changes to CIDs can be detrimental (i.e., hazards in the risk framing), beneficial, neutral, or a mixture of each across interacting system elements, regions and sectors (covered in the Working Group II Sectoral Chapters 2–8). Each sector is affected by multiple CIDs, and each CID affects multiple sectors.

Many global- and regional-scale CIDs, including extremes, have a direct relation to global warming levels (GWLs) and can thus inform the hazard component of 'Representative Key Risks' and 'Reasons for Concern' assessed by Working Group II Sixth Assessment Report. These include heat, cold, wet and dry hazards, both mean and extremes; cryospheric hazards (snow cover, ice extent, permafrost) and oceanic hazards (marine heatwaves) (*high confidence*).

For more information see the Technical Summary Sections TS1.4 and TS4.3, Chapter 12 Sections 12.1-12.4, Table 12.2, Cross-Chapter Box 12.1 and Annex.VI Climatic Impact-Driver and Extreme Indices.

Table 3: Changes in climatic impact-drivers (CIDs) until 2050, corresponding to around 2°C of global warming since the pre-industrial era. The table is a summary of confidence for CID changes in each of the Working Group I Sixth Assessment Report reference regions (continental and then subcontinent) across multiple lines of evidence: observed, attributed and projected directional changes. The colours represent their **projected** aggregate characteristic changes for the mid-21st century, which corresponds to approximately 2°C global warming. Arrows indicate *medium* to *high confidence* trends derived from **observations**, and asterisks indicate *medium* and *high confidence* in **attribution** of observed changes. This table is sourced from the Technical Summary Table TS.5.

	Climatic Impact-driver																													
	Heat and Cold				Wet and Dry								Wind				Snow and Ice						Coastal and Oceanic					Other		
	Mean air temperature	Extreme heat	Cold spell	Frost	Mean precipitation	River flood	Heavy precipitation and pluvial flood	Landslide	Aridity	Hydrological drought	Agricultural and ecological drought	Fire weather	Mean wind speed	Severe wind storm	Tropical cyclone	Sand and dust storm	Snow, glacier and ice sheet	Permafrost	Lake, river and sea ice	Heavy snowfall and ice storm	Hail	Snow avalanche	Relative sea level	Coastal flood	Coastal erosion	Marine heatwave	Ocean and lake acidity	Air pollution weather	Atmospheric CO_2 at surface	Radiation at surface
Africa																														
North Africa	↗	↗ ***	↘ ***						↗	↗	↗			3									↗		4	↗	↗		↗	
Sahara	↗	↗ **	↘ **																				↗		4	↗	↗		↗	
Western Africa	↗	↗ **	↘ **		1	↗			↗ 1	↗ 1	↗ 1												↗		4	↗	↗		↗	
Central Africa	↗				↘ 1,2						↗												↗		4	↗	↗		↗	
North Eastern Africa	↗	↗ **	↘ **		↘				1	1	1						↘						↗		4	↗	↗		↗	
South Eastern Africa	↗	↗ **							1	1	1				3		↘						↗		4	↗	↗		↗	
West Southern Africa	↗	↗ ***	↘ ***		↘	↗	↗				↗												↗		4	↗	↗		↗	
East Southern Africa	↗	↗ ***	↘ ***		↘	↗	↗				↗				3								↗		4,5	↗	↗		↗	
Madagascar	↗	↗	↘												3								↗		4,5	↗	↗		↗	

Note: There are several region-specific qualifiers/exceptions attached to some of the directions of change/confidence levels indicated above. {12.4}

Key for observational trend evidence ↗ Past upward trend (*medium* or *higher confidence*) ↘ Past downward trend (*medium or higher confidence*)

Key for attribution evidence *** *High confidence* (or more) ** *Medium confidence*

Key for level of confidence in future changes *High confidence* of increase (or more) · *Medium confidence* of increase (or more) · *Low confidence* in direction of change · *Medium confidence* of decrease · *High confidence* of decrease · Not broadly relevant

Table 3 (continued)

	Climatic Impact-driver																												
	Heat and Cold				Wet and Dry								Wind				Snow and Ice						Coastal and Oceanic					Other		
	Mean air temperature	Extreme heat	Cold spell	Frost	Mean precipitation	River flood	Heavy precipitation and pluvial flood	Landslide	Aridity	Hydrological drought	Agricultural and ecological drought	Fire weather	Mean wind speed	Severe wind storm	Tropical cyclone	Sand and dust storm	Snow, glacier and ice sheet	Permafrost	Lake, river and sea ice	Heavy snowfall and ice storm	Hail	Snow avalanche	Relative sea level	Coastal flood	Coastal erosion	Marine heatwave	Ocean and lake acidity	Air pollution weather	Atmospheric CO_2 at surface	Radiation at surface
Asia																														
Arabian Peninsula	↗	↗ ***	↘ **	↘																			↗		1	↗			↗	
West Central Asia	↗	↗ ***	↘ ***	↘	5		↗		↗		↗		↘				↘						↗		1,2	↗			↗	
West Siberia	↗	↗ ***	↘ ***	↘	↗		↗						↘				↗	↘											↗	
East Siberia	↗	↗ ***	↘ ***	↘	↗		↗						↘				↗	↘											↗	
Russian Far East	↗	↗ ***	↘ ***	↘	↗		↗										↗	↘					↗		1,2	↗	↗		↗	
East Asia	↗	↗ ***	↘ ***	↘			↗			↗	↗		↘		↗ 3				↘				↗		1,2	↗			↗	
East Central Asia	↗	↗ ***	↘ ***				↗				↗		↘					↘	↘											
Tibetan Plateau	↗	↗ ***	↘ ***	↘			↗						↘					↘											↗	
South Asia	↗	↗ ***	↘ ***	↘	↘		↗						↘				↘	↘					↗		1	↗				
South East Asia	↗	↗ ***	↘ ***		4		↗								↗ 3								↗		1,2	↗			↗	

Note: There are several region-specific qualifiers/exceptions attached to some of the directions of change/confidence levels indicated above. {12.4}

Key for observational trend evidence ↗ Past upward trend (*medium* or *higher confidence*) ↘ Past downward trend (*medium or higher confidence*)

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Key for level of confidence in future changes *High confidence* of increase (or more) | *Medium confidence* of increase (or more) | *Low confidence* in direction of change | *Medium confidence* of decrease | *High confidence* of decrease | Not broadly relevant

Table 3 (continued)

Climatic Impact-driver		Northern Australia	Central Australia	Eastern Australia	Southern Australia	New Zealand
Heat and Cold	Mean air temperature	High inc.	High inc. ↗	High inc. ↗	High inc. ↗	High inc. ↗
Heat and Cold	Extreme heat	High inc. ↗ ***	High inc. ↗ ***	High inc. ↗ ***	High inc. ↗ ***	High inc. ↗
Heat and Cold	Cold spell	High dec. ↘ ***	High dec. ↘ ***	High dec. ↘ ***	High dec. ↘ ***	High dec. ↘ **
Heat and Cold	Frost	High dec. ↘	High dec. ↘	High dec. ↘	High dec. ↘	High dec.
Wet and Dry	Mean precipitation	Low	Low	Med. dec.	Med. dec. 1	Low 2
Wet and Dry	River flood	Med. inc.	Med. inc.	Med. inc.	Med. inc.	Med. inc.
Wet and Dry	Heavy precipitation and pluvial flood	Med. inc. ↗	Med. inc.	Low	Low	Low
Wet and Dry	Landslide	Not relevant	Not relevant	Not relevant	Not relevant	Low
Wet and Dry	Aridity	Low	Low	Med. inc.	Med. inc. ↗ 3	Low 4
Wet and Dry	Hydrological drought	Low	Low	Low	Med. inc. ↗	Low
Wet and Dry	Agricultural and ecological drought	Low ↘	Low	Med. inc.	Med. inc. ↗	Low
Wet and Dry	Fire weather	High inc.	High inc.	High inc.	High inc. ↗ **	Med. inc.
Wind	Mean wind speed	Low	Low	Low	Low 7	Low 8
Wind	Severe wind storm	Low	Low	Low	Low	Low
Wind	Tropical cyclone	Low ↘ 5	Not relevant	Not relevant	Not relevant	Not relevant
Wind	Sand and dust storm	Med. inc.	Med. inc.	Med. inc.	Med. inc.	Not relevant
Snow and Ice	Snow, glacier and ice sheet	Not relevant	Not relevant	Not relevant	High dec. ↘	High dec. ↘ 6
Snow and Ice	Permafrost	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant
Snow and Ice	Lake, river and sea ice	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant
Snow and Ice	Heavy snowfall and ice storm	Not relevant	Not relevant	Not relevant	Not relevant	Low
Snow and Ice	Hail	Not relevant	Not relevant	Low	Low	Low
Snow and Ice	Snow avalanche	Not relevant	Not relevant	Not relevant	Low	Low
Coastal and Oceanic	Relative sea level	High inc. ↗	High inc. ↗	High inc. ↗	High inc. ↗	High inc. ↗
Coastal and Oceanic	Coastal flood	High inc.	High inc.	High inc.	High inc.	High inc.
Coastal and Oceanic	Coastal erosion	High inc. 7	High inc. 7	High inc. 7	High inc. 7	High inc. 7
Coastal and Oceanic	Marine heatwave	High inc. ↗	High inc. ↗	High inc. ↗	High inc. ↗	High inc. ↗
Coastal and Oceanic	Ocean and lake acidity	High inc. ↗	High inc. ↗	High inc. ↗	High inc. ↗	High inc. ↗
Other	Air pollution weather	Low	Low	Low	Low	Low
Other	Atmospheric CO_2 at surface	High inc. ↗	High inc. ↗	High inc. ↗	High inc. ↗	High inc. ↗
Other	Radiation at surface	Low	Low	Low	Low	Low

Note: There are several region-specific qualifiers/exceptions attached to some of the directions of change/confidence levels indicated above. {12.4}

Key for observational trend evidence ↗ Past upward trend (*medium* or *higher confidence*) ↘ Past downward trend (*medium or higher confidence*)

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Key for level of confidence in future changes *High confidence* of increase (or more) | *Medium confidence* of increase (or more) | *Low confidence* in direction of change | *Medium confidence* of decrease | *High confidence* of decrease | Not broadly relevant

Table 3 (continued)

	Climatic Impact-driver																													
	Heat and Cold				Wet and Dry								Wind				Snow and Ice						Coastal and Oceanic					Other		
	Mean air temperature	Extreme heat	Cold spell	Frost	Mean precipitation	River flood	Heavy precipitation and pluvial flood	Landslide	Aridity	Hydrological drought	Agricultural and ecological drought	Fire weather	Mean wind speed	Severe wind storm	Tropical cyclone	Sand and dust storm	Snow, glacier and ice sheet	Permafrost	Lake, river and sea ice	Heavy snowfall and ice storm	Hail	Snow avalanche	Relative sea level	Coastal flood	Coastal erosion	Marine heatwave	Ocean and lake acidity	Air pollution weather	Atmospheric CO_2 at surface	Radiation at surface
Central and South America																														
Southern Central America	↗	↗ **	↘ **												2								↗		3	↗	↗		↗	
North-Western South America	↗	↗ ***	↘ ***																				↗		3,4	↗	↗		↗	
Northern South America	↗	↗ **	↘ **												2								↗		3,4	↗	↗		↗	
South American Monsoon	↗	↗ **	↘ **			↗ 1																							↗	
North-Eastern South America	↗	↗ **	↘ **		↘						↗												↗		3,4	↗	↗		↗	
South-Western South America	↗	↗ **	↘ **	↘					↗														↗		3	↗	↗		↗	
South-Eastern South America	↗	↗ ***	↘ ***	↘	↗		↗			↘													↗		3	↗	↗		↗	
Southern South America	↗			↘																			↗		3	↗	↗		↗	

Note: There are several region-specific qualifiers/exceptions attached to some of the directions of change/confidence levels indicated above. {12.4}

Key for observational trend evidence ↗ Past upward trend (*medium* or *higher confidence*) ↘ Past downward trend (*medium or higher confidence*)

Key for attribution evidence *** *High confidence* (or more) ** *Medium confidence*

Key for level of confidence in future changes *High confidence* of increase (or more) | *Medium confidence* of increase (or more) | *Low confidence* in direction of change | *Medium confidence* of decrease | *High confidence* of decrease | Not broadly relevant

Table 3 (continued)

	Climatic Impact-driver																													
	Heat and Cold				Wet and Dry								Wind				Snow and Ice						Coastal and Oceanic					Other		
	Mean air temperature	Extreme heat	Cold spell	Frost	Mean precipitation	River flood	Heavy precipitation and pluvial flood	Landslide	Aridity	Hydrological drought	Agricultural and ecological drought	Fire weather	Mean wind speed	Severe wind storm	Tropical cyclone	Sand and dust storm	Snow, glacier and ice sheet	Permafrost	Lake, river and sea ice	Heavy snowfall and ice storm	Hail	Snow avalanche	Relative sea level	Coastal flood	Coastal erosion	Marine heatwave	Ocean and lake acidity	Air pollution weather	Atmospheric CO_2 at surface	Radiation at surface
Europe																														
Mediterranean	↗	↗ ***	↘ ***			↘	5			↗ **	↗ **		↘ 6	7			↘						↗		2	↗	↗		↗	
Western and Central Europe	↗	↗ ***	↘ ***		↗	↗	↗	4			↗		↘				↘	↘					↗		2	↗	↗		↗	
Eastern Europe	↗	↗ ***	↘ ***		↗		↗						↘				↘												↗	
Northern Europe	↗	↗ ***	↘ ***		↗	↘ 1	↗ ***			↘			↘				↘	↘					↗	8	2,3	↗	↗		↗	
North America																														
North Central America	↗	↗ **	↘ **						↗			↗											↗	↗	2	↗	↗		↗	
Western North America	↗	↗ **	↘ **		3		5	5	4,7		↗ 6,7 **	↗ 6,7	↘	8		↗ 6	↘ 1		↘	1		1	↗	↗ 5	2	↗	↗		↗	
Central North America	↗				↗		↗ **		7		7	7	↘	8		4	↘		↘				↗	↗	2	↗	↗		↗	
Eastern North America	↗				↗ 5		↗					7	↘	8			↘ 1		↘	1		1	↗	↗	2	↗	↗		↗	
North-Eastern North America	↗	↗ ***	↘ ***	↘	5				5		6,7	6,7		8			↘ 1,6	↘	↘			1	4	↗ 4,6	2,6	↗	↗		↗	
North-Western North America	↗	↗ ***	↘ ***	↘	5			6	5		6,7	↗ 6,7		8			↘ 1	↘	↘			1,6	↗ 9	↗	2	↗	↗		↗	

Note: There are several region-specific qualifiers/exceptions attached to some of the directions of change/confidence levels indicated above. {12.4}

Key for observational trend evidence ↗ Past upward trend (*medium* or *higher confidence*) ↘ Past downward trend (*medium or higher confidence*)

Key for attribution evidence *** *High confidence* (or more) ** *Medium confidence*

Key for level of confidence in future changes *High confidence* of increase (or more) | *Medium confidence* of increase (or more) | *Low confidence* in direction of change | *Medium confidence* of decrease | *High confidence* of decrease | Not broadly relevant

Table 3 (continued)

	Climatic Impact-driver: Heat and Cold				Wet and Dry								Wind				Snow and Ice						Coastal and Oceanic					Other		
	Mean air temperature	Extreme heat	Cold spell	Frost	Mean precipitation	River flood	Heavy precipitation and pluvial flood	Landslide	Aridity	Hydrological drought	Agricultural and ecological drought	Fire weather	Mean wind speed	Severe wind storm	Tropical cyclone	Sand and dust storm	Snow, glacier and ice sheet	Permafrost	Lake, river and sea ice	Heavy snowfall and ice storm	Hail	Snow avalanche	Relative sea level	Coastal flood	Coastal erosion	Marine heatwave	Ocean and lake acidity	Air pollution weather	Atmospheric CO_2 at surface	Radiation at surface
Small Islands																														
Caribbean	↗	↗ **													5								↗		6	↗	↗		↗	
Pacific	↗	↗ **1			2		3		4						5								↗		6	↗	↗		↗	
Polar Terrestrial Regions																														
Greenland and Iceland	↗	↗ **	↘ **			↗	↗		↘ 3			2,3					↘ 1	↘	↘				↗ 5				↗		↗	
Arctic North Europe	↗	↗				↗			↘ 3			2,3					↘ 1	↘	↘				↗ 6		7		↗		↗	
Russian Arctic	↗	↗ **	↘ **			↗			↘ 3			2,3					↘ 1,4		↘						7		↗		↗	
Arctic North-Western North America	↗					↗			↘ 3			2,3					↘ 1,4	↘	↘						7		↗		↗	
Arctic North-East North America	↗	↗				↗			↘ 3			2,3					↘ 1,4	↘	↘				↘				↗		↗	
West Antarctica																	↘ 1,4										↗		↗	
East Antarctica																											↗		↗	

Note: There are several region-specific qualifiers/exceptions attached to some of the directions of change/confidence levels indicated above. {12.4}

Key for observational trend evidence ↗ Past upward trend (*medium* or *higher confidence*) ↘ Past downward trend (*medium or higher confidence*)

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Key for level of confidence in future changes *High confidence* of increase (or more) | *Medium confidence* of increase (or more) | *Low confidence* in direction of change | *Medium confidence* of decrease | *High confidence* of decrease | Not broadly relevant

Table 3 (continued)

	Climatic Impact-driver					
	Mean ocean temperature	**Marine heatwave**	**Ocean acidity**	**Ocean salinity**	**Dissolved oxygen**	**Sea ice**
Oceans						
Arctic Ocean	↗		↗			↘ ***
South Pacific Ocean	↗	↗	↗			
Equatorial Pacific Ocean	↗	↗	↗			
North Pacific Ocean	↗	↗	↗			
South Atlantic Ocean	↗	↗	↗			
Equatorial Atlantic Ocean	↗	↗	↗			
North Atlantic Ocean	↗	↗	↗			
Equatorial Indian Ocean	↗	↗	↗			
South Indian Ocean	↗	↗	↗			
Arabian Sea	↗	↗	↗			
Bay of Bengal	↗	↗	↗			
Southern Ocean						

Note: There are several region-specific qualifiers/exceptions attached to some of the directions of change/confidence levels indicated above. {12.4}

Key for observational trend evidence ↗ Past upward trend (*medium* or *higher confidence*) ↘ Past downward trend (*medium or higher confidence*)

Key for attribution evidence *** *High confidence* (or more) ** *Medium confidence*

Key for level of confidence in future changes *High confidence* of increase (or more) | *Medium confidence* of increase (or more) | *Low confidence* in direction of change | *Medium confidence* of decrease | *High confidence* of decrease | Not broadly relevant

Notes:

Africa (projections)

1. Contrasted regional signal: drying in western portions and wetting in eastern portions
2. *Likely* increase over the Ethiopian Highlands
3. *Medium confidence* of decrease in frequency and increase in intensity
4. Along sandy coasts and in the absence of sufficient sediment supply from terrestrial or offshore sources
5. Substantial parts of the East Southern Africa and Madagascar coast are projected to prograde if present-day ambient shoreline change rates continue

Asia (projections)

1. Along sandy coasts and in the absence of additional sediment sinks/sources or any physical barriers to shoreline retreat.
2. Substantial parts of the coasts in these regions are projected to prograde if present-day ambient shoreline change rates continue
3. Tropical cyclones decrease in number but increase in intensity
4. *High confidence* of decrease in Indonesia (Atlas.5.4.5)
5. *Medium confidence* of decreasing in summer and increasing in winter

Australasia (projections)

1. *High confidence* of decrease in the south-west of the state of Western Australia
2. *Medium confidence* of decrease in north and east and increase in south and west
3. *High confidence* of increase in the south-west of the state of Western Australia
4. *Medium confidence* of increase in the north and east and decrease in south and west
5. *Low confidence* of increasing intensity, and *high confidence* of decreasing occurrence
6. *High confidence* of decrease in glacier volume, *medium confidence* of decrease in snow
7. Along sandy coasts and in the absence of additional sediment sinks/sources or any physical barriers to shoreline retreat

Central and South America (projections)

1. Increase in extreme flow in the Amazon basin
2. Tropical cyclones decrease in number but increase in intensity
3. Along sandy coasts and in the absence of additional sediment sinks/sources or any physical barriers to shoreline retreat.
4. Substantial parts of the North-Western South America, Northern South America and North-Eastern South America coasts are projected to prograde if present-day ambient shoreline change rates continue

Europe (projections)

1. Excluding southern United Kingdom
2. Along sandy coasts and in the absence of additional sediment sinks/sources or any physical barriers to shoreline retreat
3. The Baltic Sea shoreline is projected prograde if present-day ambient shoreline change rates continue.
4. For the Alps, conditions conducive to landslides are expected to increase
5. *Low confidence* of decrease in the southernmost part of the region
6. General decrease except in Aegean Sea
7. *Medium confidence* of decrease in frequency and increase in intensities
8. Except in the Northern Baltic Sea region

North America (projections)

1. Snow may increase in some high elevations and during the cold season and decrease in other seasons and at lower elevations
2. Along sandy coasts and in the absence of additional sediment sinks/sources or any physical barriers to shoreline retreat.
3. Increasing in northern regions and decreasing toward the south
4. Decreasing in northern regions and increasing toward the south
5. Higher confidence in northern regions and lower toward the south
6. Higher confidence in southern regions and lower toward the north
7. Higher confidence in increase for some climatic impact-driver indices during summertime
8. Increase in convective conditions but decrease in winter extratropical cyclones
9. Relative sea level rise reduced given land uplift in Southern Alaska

Small Islands (projections)

1. *Very high confidence* in the direction of change, but *low* to *medium confidence* in the magnitude of change due to model uncertainty
2. Decrease in eastern Pacific and southern Pacific subtropics, but increase in parts of western and equatorial Pacific; with seasonal variation in future changes
3. *High confidence* in increase in extreme rain frequency and intensity in western tropical Pacific; *low confidence* in magnitude of change due to model bias
4. Increase in southern Pacific
5. Increase in intensity; decrease in frequency except over central North Pacific.
6. Along sandy coasts and in the absence of additional sediment sinks/sources or any physical barriers to shoreline retreat.

Polar Terrestrial Regions (projections)

1. Snow may increase in some high elevations and during the cold season and decrease in other seasons and at lower elevations
2. Higher confidence in southern regions and lower toward the north
3. Higher confidence in increase for some climatic impact-driver indices during summertime
4. Glaciers decline even as some regional snow climatic impact-driver indices increase
5. Decreasing in west and increasing in east
6. Except for Northern Baltic Sea coasts where relative sea levels fall
7. Along sandy coasts and in the absence of additional sediment sinks/sources or any physical barriers to shoreline retreat

Regional Summaries of CID Changes

With further global warming, every region is projected to increasingly experience concurrent and multiple changes in CIDs. Changes would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels.

With 2°C global warming, and as early as the mid-21st century, a wide range of CIDs are expected to show simultaneous region-specific changes with *high* or *medium confidence*. These changes are relative to the recent past and relate to the sub-continental regions as defined by the Working Group I Sixth Assessment Report report. All regions are projected to experience changes in at least 5 CIDs. Almost all (96%) are projected to experience changes in at least 10 CIDs and half in at least 15 CIDs (Table 3).

- Increases in heat CIDs, decreases in cold CIDs (*high confidence*).
    - In almost all regions.
- Increases in drought, aridity and fire weather (*high confidence*)
    - In a number of regions in Southern Africa, the Mediterranean, North Central America, Western North America, the Amazon regions, South-Western South America, and Australia
    - Will affect a wide range of sectors, including agriculture, forestry, health and ecosystems.
- Decreases in snow and ice or increases in pluvial/river flooding (*high confidence*)
    - In a number of regions in North-Western, Central and Eastern North America, Arctic regions, North-Western South America, Northern and Central Western Europe, Siberia, Central, South and East Asia, Southern Australia and New Zealand
    - Will affect sectors such as winter tourism, energy production, river transportation and infrastructure.

For more information see the Summary for Policymakers Sections B.3 and C.2, the Technical Summary Section TS.4.3.2, Chapter 11 Section 11.9, Chapter 12 Section 12.4, and Chapter 12 Table 12.2.

Low Confidence Does not Mean that Nothing Will Happen

There is currently *low confidence* in regional assessments of past and future changes of some damaging hazards such as hail, ice storms, severe storms, sand and dust storms, heavy snowfall and avalanches. These high-impact hazards generally span spatial and temporal scales that are not resolved by climate or impact models and do not benefit from long and homogeneous observations. For convective events (hail, tornadoes, lightning storms, downdrafts), it is currently not possible to quantitatively predict changes in odds. However, in some regions (e.g., Europe, North America), studies based on indirect indices have shown

that climate change is inducing a higher frequency of more favorable environments for the development of convective events. Such indices are based for instance on the Convective Available Potential Energy (CAPE), the “Lifted Index”, which are widely used as proxies of atmospheric static instability in meteorology to predict thunderstorms, together with wind shear (necessary for supercells and tornadoes formation), or by statistical models linking for instance reported hail events with weather variables.

For more information see the Summary for Policymakers Section C.2, the Technical Summary Section TS4.3.2, and Chapter 12 Table 12.2.

Visualizing Regional CID Changes

The Interactive Atlas allows users to visualize projected CIDs changes across regions (see Figure 11). This tool lets you see how every region is projected to increasingly experience a specific *combination* of multiple changes, as further warming continues. Figure 11 shows how the four ‘dry’ climate-impact drivers (aridity, hydrological drought, agricultural and ecological drought, fire weather) are estimated to change by mid-century assuming 2°C of global warming relative to the pre-industrial.

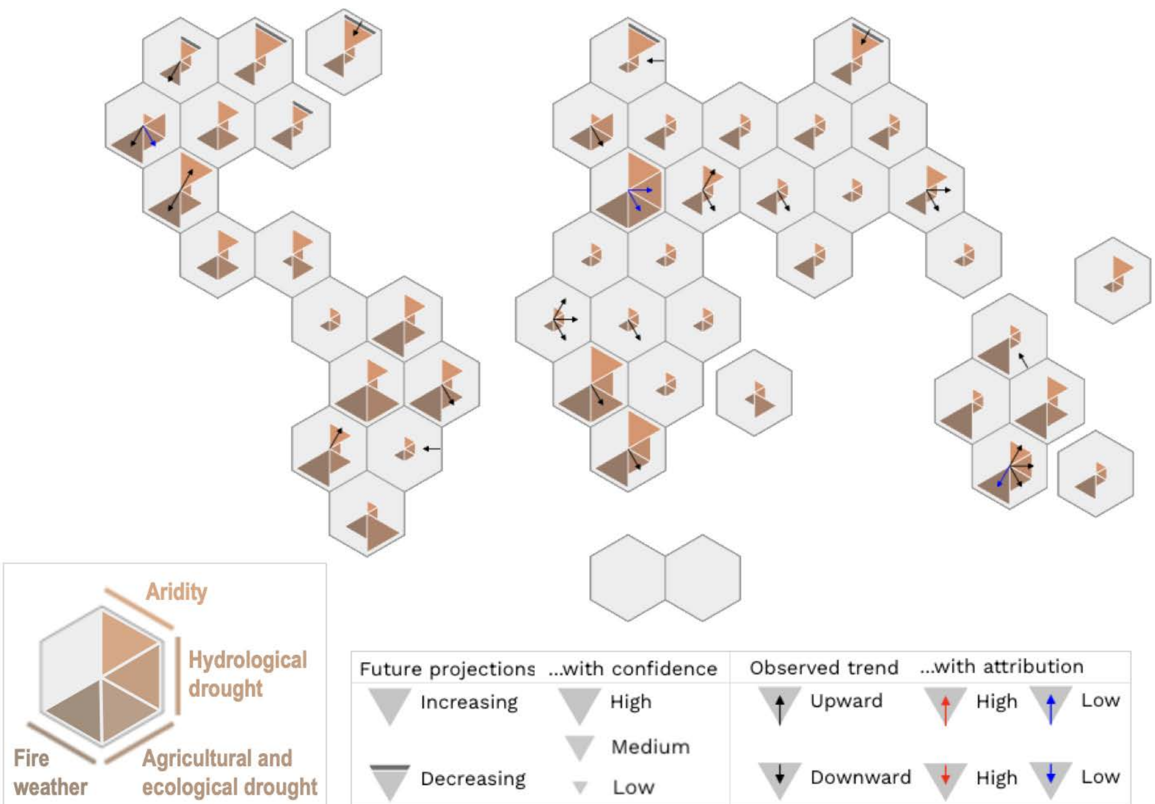

Figure 11: Synthesis of climatic-impact driver (CID) information for the four ‘dry’ climate-impact drivers (aridity, hydrological drought, agricultural and ecological drought, fire weather) across each of the sub-continental reference regions. Changes correspond to the two categories for which there is evidence over the sub-continental reference regions: Regional historical trends and attribution,

indicating upward or downward trends, with or without attribution; and projected changes and confidence, indicating increasing/decreasing projected changes with *low/medium/high confidence* around 2050 if 2°C of global warming is reached relative to pre-industrial. This figure is sourced from the WGI Interactive Atlas: https://interactive-atlas.ipcc.ch/permalink/d5xU9Jlh. A tabular version of this figure is also available through this link.

For more information see the Interactive Atlas: https://interactive-atlas.ipcc.ch/regional-synthesis

Most Regions Will See Continued Relative Sea Level Rise

Regional mean relative sea level rise will continue throughout the 21st century, except in a few regions with substantial geologic land uplift rates (Table 3). Approximately two-thirds of the global coastline has a projected regional relative sea level rise within ±20% of the global mean increase (*medium confidence*). Relative sea level rise contributes to increases in the frequency and severity of coastal flooding in low-lying areas, to coastal erosion along most sandy coasts, in the absence of additional sediment sources or physical obstacles to shoreline retreat (*high confidence*).

Risks related to coastal effects of sea level rise will continue even for stabilized warming levels due to the slow responses of glaciers and ice sheets melting. Relative sea level rise will continue during the 21st century, contributing to increased coastal flooding in low-lying areas and coastal erosion along most sandy coasts (in the absence of adaptation actions). As global mean sea level will continue to rise beyond 2100 (*high confidence*), CIDs closely related to sea level rise (i.e., relative sea level rise, coastal flooding and coastal erosion) will also increase beyond 2100.

Regional sea level projections can be visualized and downloaded from the NASA/IPCC Sea Level Projection Tool (https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool). Similarly, the Coastal Futures online tool (http://coastal-futures.org/) visualizes changes to coastal CIDs. The Annex.I Data of this summary provides more information on these online tools.

For more information see the Summary for Policymakers Section C.2, the Technical Summary Box TS.4, Chapter 9 Section 9.6 and Chapter 12 Section 12.4.

Regional Monsoons Changes Affect Precipitation and Season

A warmer climate intensifies very wet and very dry weather and climate events and seasons, with implications for flooding or drought – depending on changes in regional atmospheric circulation (*high confidence*). Precipitation is very likely to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and limited areas in the tropics. Monsoon precipitation is projected to increase in the mid- to long term at global scale, particularly over South and South East Asia, East Asia and West Africa apart from the far west Sahel (*high confidence*).The monsoon season

is projected to have a delayed onset over North and South America and West Africa (*high confidence*) and a delayed retreat over West Africa (*medium confidence*).

For more information see the Summary for Policymakers Section B.3, the Technical Summary Box TS.13, Chapter 8 Box 8.2 and Section 8.4.2, and Chapter 4 Section 4.5.1.

Limiting Climate Change

Strong reductions in greenhouse gas emissions would greatly limit the increase in the frequency of extreme sea level events, heavy precipitation and pluvial flooding, and exceedance of such dangerous heat thresholds, while limiting the number of regions where such exceedances occur, relative to the consequences of increased emissions (*high confidence*).

Global warming is almost linearly proportional to the cumulative net amount of carbon dioxide that has been and continues to be emitted into the atmosphere by human activities (*high confidence*).

To stabilize global warming, global carbon dioxide emissions have to be reduced to net zero levels. Net zero carbon dioxide is a state in which any remaining emission of carbon dioxide by human activities is compensated by an equal amount of carbon dioxide removal by human activities. Once global carbon dioxide emissions reach net zero levels, our best scientific understanding tells us that no further warming will occur. However, there is an uncertainty surrounding this best estimate, and some additional warming or cooling could occur once net zero carbon dioxide emissions are reached – on the order of about 15% of the total warming experienced up to that point. The characteristic that to first order no further warming or cooling occurs when net zero carbon dioxide emissions are reached implies that requirements for limiting warming at specific levels can be expressed in the form of a total or remaining carbon budget (Table 4). (*high confidence*)

Historical cumulative carbon dioxide emissions from 1850 to 2019 are 2390 (± 240) gigatonnes of carbon dioxide (GtCO2). Human-caused warming for this period is 1.07 (0.8–1.3) °C [5]. The remaining carbon budget is about 500 GtCO2 to limit global warming to around 1.5°C above pre-industrial (with a 50% chance). This increases to about 1350 GtCO2 to limit global warming to around 2°C, also with 50% *likelihood*. Our choice on how we reduce non-carbon dioxide greenhouse gases (such as methane, nitrous oxide, ozone precursors, sulphur dioxide etc.) can affect the remaining carbon budget by about 220 GtCO2.

Table 4: Estimates of historical carbon dioxide emissions and remaining carbon budgets for 1.5°C, 1.7°C, and 2°C global warming. Estimated remaining carbon budgets are calculated from the beginning of 2020 and extend until global net zero carbon dioxide emissions are reached. They refer to carbon dioxide emissions, while accounting for the global warming effect of non-carbon dioxide emissions. Global warming in this table refers to human-caused global surface temperature increase, which excludes the impact of natural variability on global temperatures in individual years. This table is sourced from the Summary for Policymakers Table SPM.2.

5 All ranges here are assessed to be *likely*.

Global warming level (°C)	Additional warming compared to today (°C)	Estimated Remaining Carbon Budget from today (GtCO2) likelihood of limiting			Role of non-carbon dioxide emissions reductions (GtCO2)
		⅓ chance	½ chance	⅔ chance	
1.5	0.43	650	500	400	+/- 220
1.7	0.63	1050	850	700	
2	0.93	1700	1350	1150	

Every emission of carbon dioxide will further increase global temperatures. It is only when net zero carbon dioxide emissions levels are reached that the global warming caused by carbon dioxide will stabilize. Cumulative carbon dioxide emissions are proportional to global warming because a fraction of emissions of carbon dioxide remain in the atmosphere for a very long time. In contrast, short-lived climate forcers, such as methane, have a shorter lifetime in the atmosphere and their contribution to global warming is more closely related to their annual emission level. Thus, if emissions of methane decline, so does the global warming they cause. (*high confidence*)

For more information see the Summary for Policymakers Section D1, the Technical Summary Section TS.3.3 and Chapter 5 Section 5.5.2.

The Working Group I Sixth Assessment Report stresses that strong, rapid and sustained reductions in methane emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality (because methane oxidation leads to ozone production). The report shows how strategies integrating climate and air quality can achieve multiple benefits and limit trade-offs.

For more information see the Summary for Policymakers Section D1, the Technical Summary Box TS.7 and Chapter 6 Section 6.6.

ANNEX.I Data

Guidance on Using Climate Data

Accessing Climate Data

The Working Group I Sixth Assessment Report presents the current state of knowledge related to best practices to distill context-specific, actionable climate information.

This includes the methodological process to construct and synthesize climate information and the co-production that needs to take place to allow this information to inform action, in an interactive process involving multiple stakeholders (Figure Annex 1).

Regional Climate Data

Regional climate, including extreme events, is determined by weather and climate phenomena across all scales ranging from planetary to continental to local, as well as external forcings such as changes in greenhouse gases, aerosols and land use. Understanding *observed* regional climate change and variability is based on the availability and analysis of multiple observational datasets that are suitable for evaluating the phenomena of interest (e.g., extreme events), including accounting for observational uncertainty. To *attribute* observed changes and events to large- and regional-scale anthropogenic and natural drivers, suitable observational data are combined with suitable climate model simulations of past climatic changes. Understanding and *projecting* regional climate change relies on the use of data sources and methodologies that are fit for the specific purpose. Future simulations with many climate models (multi-model ensembles) are then used to generate and quantify ranges of projected regional climate responses. Ensembles for regional climate projections should be selected such that models unrealistically simulating processes relevant for a given application are discarded, but at the same time, the chosen ensemble spans an appropriate range of projection uncertainties (*high confidence*). Multi-model mean and ensemble spread are not a full measure of the range of projection uncertainty and are not sufficient to characterize low-likelihood, high-impact changes or situations where different models simulate substantially different or even opposite changes. Depending on the purpose, different observational datasets and model types may be required: for instance, gridded observational datasets based on a sparse rain-gauge network may provide insight into the main features of mean precipitation, but may fail to represent local extreme rainfall. Similarly, global climate models may provide insight into changes in mean climate or selected extreme events such as large-scale storms, heatwaves and droughts, but very-high-resolution regional climate models may be required to represent changes in coastal weather and local extreme rainfall or even urban climate.

For more information see the Technical Summary Section TS.4.1.1 and Chapter 10 Sections 10.3.2 and 10.3.3.

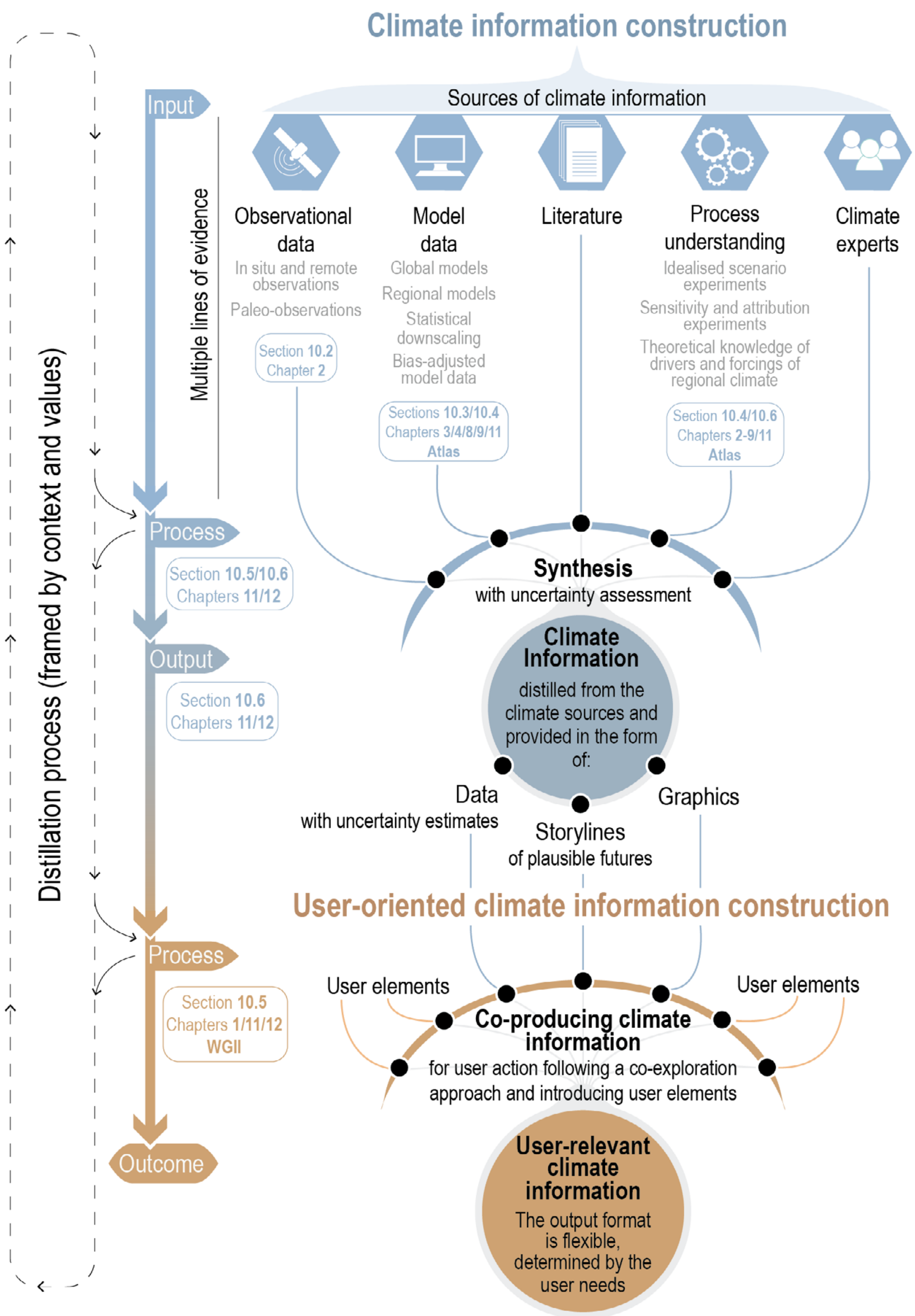

Figure Annex 1: Diagram of the processes leading to the construction of regional climate information (green) and user-relevant regional climate information (orange). The chapter sections and the other chapters of the report involved in each step are indicated in rectangles. WGII stands for Working Group II. This figure is sourced from Chapter 10 Figure 10.1.

Data Access Through the Interactive Atlas

The WGI Interactive Atlas supports the regional chapters' assessments and contains climate information for all regions.

A novel part of the Working Group I Sixth Assessment Report report, the Interactive Atlas (https://interactive-atlas.ipcc.ch) allows you to explore observational products, paleoclimate data and global and regional model data, both global and regional datasets, different variables, indices, regions, baselines, scenarios, time horizons and global warming levels.

Key variables from the atmosphere (daily mean, minimum and maximum surface temperatures and precipitation, surface air pollutants) and ocean (sea surface temperature, sea level rise, sea ice concentration, pH) are available in the Interactive Atlas, along with a number of extreme indices (used in Chapter 11; see Annex VI, Table A.VI.1) and climatic impact-drivers (used in Chapter 12; see Annex VI, Table A.VI.1).

The Interactive Atlas is based on open source software (the R package climate4R) and implements the FAIR data principles of ensuring data are findable, accessible, interoperable, and reusable. The code reproducing some intermediate products (e.g., warming levels, regridded indices for common grids, etc.) and some of the figures underpinning the assessment done in the Atlas chapter (regional synthesis figures) and in the Interactive Atlas (currently the spatial maps) are available from the IPCC-WG1 GitHub repository (https://github.com/IPCC-WG1/Atlas; doi: 10.5281/zenodo.5171760).

Interactive Atlas available data

Model Data Variables:

- Mean temperature (T)
- Minimum temperature (TN)
- Minimum of minimum temperatures (TNn)
- Frost days (FD)
- Heating degree days (HD)
- Maximum temperature (TX)
- Maximum of maximum temperatures (TXx)
- Days with TX above 35ºC (TX35)
- Bias Adjusted TX35
- Days with TX above 40ºC (TX40)
- Bias Adjusted TX40
- Cooling degree days (CD)
- Total precipitation (PR)

- Maximum 1-day precipitation (RX1day)
- Maximum 5-day precipitation (RX5day)
- Consecutive Dry Days (CDD)
- Standardized Precip Index (SPI-6)
- Surface wind
- Snowfall
- Surface ozone
- ERF (due to aerosols)
- Surface particulate matter (PM2.5)
- Sea surface temperature (SST)
- pH at surface (pH)
- Sea ice coverage
- Sea level rise (SLR)
- carbon dioxide anthropogenic emissions
- Population density

Observational Product Variables:

- Mean temperature (T)
- Maximum temperature (TX)
- Total precipitation (PR)
- Snowfall
- Surface wind

Spatially aggregated regional information is provided for different **predefined regional sets**:

- The sub-continental Working Group I Sixth Assessment Report reference regions.
- Working Group II Sixth Assessment Report continental regions
- Monsoon regions
- Major river basins
- Small-island regions
- Ocean biological activity regions

Information is available across the **five core illustrative scenarios** used in the report. Future projections can be analyzed in the Interactive Atlas using both **time-slices** (near-, mid- and

long-term periods: 2021-2040, 2041-2060 and 2081-2100, respectively) and **global warming levels** (1.5°C, 2°C, 3°C and 4°C).

The Interactive Atlas allows downloading the products (maps, time series, scatter plots, etc.) in different formats (bitmap or PDF), as well as the data underlying the maps (in GIS format). The data is made available under a Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/).

Code and Data From the Report Figures

It is intended that all the data and code for all figures of the Working Group I Sixth Assessment Report will be made available online for users to access. Note that this is an ongoing process and as such not all datasets may be available at the time of publication.

The data for report figures are being archived from the UK Centre for Environmental Data Analysis (CEDA) and can be accessed via https://catalogue.ceda.ac.uk/uuid/3234e9111d4f4354af00c3aaecd879b7. In each case, click on 'Datasets' under Related Records to view the catalogue records for report figures and to access the corresponding data. The abstract field of these catalogue records contains detailed information about the data, including how they should be cited. The data are made available under a Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/).

Code is being made available on the WGI Github account and can be accessed via https://github.com/IPCC-WG1. Figures are saved under each chapter they appear in. Documentation support and readme files are available for each figure.

Other Data Tools

The NASA/IPCC Sea Level Projection Tool (https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool) allows users to visualize and download the sea level projection data from the IPCC Sixth Assessment Report. The tool allows users to view both global and regional sea level projections from 2020 to 2150, along with how these projections differ depending on future scenarios. Users can click on tide gauge locations and points anywhere in the ocean to obtain the IPCC projection of sea level for that individual location.

Users interested in downloading the complete AR6 projections used in this tool can access the dataset at https://doi.org/10.5281/zenodo.5914710.

The Coastal Futures Tool

Coastal Futures (CoFu, http://coastal-futures.org/) is an interactive online viewer that combines several published datasets of 21st century projections of coastal climatic impact-drivers assessed in the Working Group I Sixth Assessment Report. It enables users to see how climatic impact-drivers such as relative sea level rise, extreme sea levels, coastal flooding, shoreline change and extreme waves are projected to change all over the world. The Coastal Futures (CoFu) viewer is created and maintained by IHE Delft, The Netherlands (see Team CoFu) through a collaboration between the Department of Coastal and Urban Risk & Resilience, and the Department of Hydroinformatics and Socio-Technical Innovation.

ANNEX.II Glossary

All definitions listed below, unless stated otherwise, come from the Working Group I Sixth Assessment Report Annex.VII Glossary.

Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, in order 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 and its effects.

Aerosol A suspension of airborne solid or liquid particles, with typical particle size in the range of a few nanometres to several tens of micrometres and atmospheric lifetimes of up to several days in the troposphere and up to years in the stratosphere. The term aerosol, which includes both the particles and the suspending gas, is often used in this report in its plural form to mean 'aerosol particles'. Aerosols may be of either natural or anthropogenic origin in the troposphere; stratospheric aerosols mostly stem from volcanic eruptions. Aerosols can cause an effective radiative forcing directly through scattering and absorbing radiation (aerosol–radiation interaction), and indirectly by acting as cloud condensation nuclei or ice nucleating particles that affect the properties of clouds (aerosol–cloud interaction), and upon deposition on snow- or ice-covered surfaces. Atmospheric aerosols may be either emitted as primary particulate matter or formed within the atmosphere from gaseous precursors (secondary production). Aerosols may be composed of sea salt, organic carbon, black carbon (BC), mineral species (mainly desert dust), sulphate, nitrate and ammonium or their mixtures.

AR6 (Sixth Assessment Report): An IPCC assessment report is published once every 8-10 years. Since its establishment in 1988, the IPCC has completed five Assessment Reports and is now on its sixth (AR6). The Sixth Assessment Report consists of contributions from each of the three IPCC Working Groups, three Special Reports, and a Synthesis Report (SYR), which integrates the Working Group contributions and the Special Reports produced in the cycle.

Breadbaskets: Breadbaskets are the part of a country or region that produces large amounts of food, especially grain, for the rest of the country or region. (Definition from the Oxford Advanced American Dictionary)

Climate extreme (extreme weather or climate event): The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., high temperature, drought, or heavy rainfall over a season). For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes'.

Climate prediction: A climate prediction or climate forecast is the result of an attempt to produce (starting from a particular state of the climate system) an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual or decadal time scales. Because the future evolution of the climate system may be highly sensitive to initial conditions, has chaotic elements and is subject to natural variability, such predictions are usually probabilistic in nature.

Climate projection: Simulated response of the climate system to a scenario of future emissions or concentrations of greenhouse gases (GHGs) and aerosols and changes in land use, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/ radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized.

Climate simulation ensemble: A group of parallel model simulations characterizing historical climate conditions, climate predictions, or climate projections. Variation of the results across the ensemble members may give an estimate of modelling-based uncertainty. Ensembles made with the same model but different initial conditions characterize the uncertainty associated with internal climate variability, whereas multi-model ensembles including simulations by several models also include the effect of model differences. Perturbed parameter ensembles, in which model parameters are varied in a systematic manner, aim to assess the uncertainty resulting from internal model specifications within a single model. Remaining sources of uncertainty unaddressed with model ensembles are related to systematic model errors or biases, which may be assessed from systematic comparisons of model simulations with observations wherever available. Also see Climate prediction and Climate projection definitions.

Climate variability: Deviations of climate variables from a given mean state (including the occurrence of extremes, etc.) at all spatial and temporal scales beyond that of individual weather events. Variability may be intrinsic, due to fluctuations of processes internal to the climate system (internal variability), or extrinsic, due to variations in natural or anthropogenic external forcing (forced variability).

> **Decadal variability**: Decadal variability refers to climate variability on decadal time scales.
>
> **Internal variability**: Fluctuations of the climate dynamical system when subject to a constant or periodic external forcing (such as the annual cycle). See also Climate variability.
>
> **Natural variability**: Natural variability refers to climatic fluctuations that occur without any human influence, that is, internal variability combined with the response to external natural factors such as volcanic eruptions, changes in solar activity and, on longer time scales, orbital effects and plate tectonics.

Climatic impact-driver (CID): Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral or a mixture of each across interacting system elements and regions.

Compound weather/climate events: The terms 'compound events', 'compound extremes' and 'compound extreme events' are used interchangeably in the literature and this report and refer to the combination of multiple drivers and/or hazards that contributes to societal and/or environmental risk (Zscheischler et al., 2018).

Driver: One of the main things that influence something or cause it to make progress (i.e., climate driver). (Definition taken from the Oxford Advanced American Dictionary)

Drought: An exceptional period of water shortage for existing ecosystems and the human population (due to low rainfall, high temperature, and/or wind).

> **Agricultural and ecological drought**: Depending on the affected biome: a period with abnormal soil moisture deficit, which results from combined shortage of precipitation and excess evapotranspiration, and during the growing season impinges on crop production or ecosystem function in general.
>
> **Hydrological drought**: A period with large runoff and water deficits in rivers, lakes and reservoirs.
>
> **Meteorological drought**: A period with an abnormal precipitation deficit.

Emergence (of the climate signal): Emergence of a climate change signal or trend refers to when a change in climate (the 'signal') becomes larger than the amplitude of natural or internal variations (defining the 'noise'), This concept is often expressed as a 'signal-to-noise' ratio and emergence occurs at a defined threshold of this ratio (e.g., S/N > 1 or 2). Emergence can refer to changes relative to a historical or modern baseline (usually at least 20 years long) and can also be expressed in terms of time (time of emergence) or in terms of a global warming level. Emergence is also used to refer to a time when we can expect to see a response of reducing greenhouse gas emissions (emergence with respect to mitigation). Emergence can be estimated using observations and/or model simulations.

> **Time of emergence (ToE):** Time when a specific anthropogenic signal related to climate change is statistically detected to emerge from the background noise of natural climate variability in a reference period, for a specific region (Hawkins and Sutton, 2012).

Evapotranspiration: The combined processes through which water is transferred to the atmosphere from open water and ice surfaces, bare soil, and vegetation that make up the Earth's surface.

Extreme/heavy precipitation event: An extreme/heavy precipitation event is an event that is of very high magnitude with a very rare occurrence at a particular place. Types of extreme precipitation may vary depending on its duration, hourly, daily or multi-days (e.g., 5 days), though all of them qualitatively represent high magnitude. The intensity of such events may be defined with block maxima approach such as annual maxima or with peak over threshold approach, such as rainfall above 95th or 99th percentile at a particular space.

Global warming: Global warming refers to the increase in global surface temperature relative to a baseline reference period, averaging over a period sufficient to remove interannual

variations (e.g., 20 or 30 years). A common choice for the baseline is 1850–1900 (the earliest period of reliable observations with sufficient geographic coverage), with more modern baselines used depending upon the application.

Greenhouse effect: The infrared radiative effect of all infrared absorbing constituents in the atmosphere. Greenhouse gases (GHGs), clouds, and some aerosols absorb terrestrial radiation emitted by the Earth's surface and elsewhere in the atmosphere. These substances emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers because of the decline of temperature with altitude in the troposphere and the consequent weakening of emission. An increase in the concentration of GHGs increases the magnitude of this effect; the difference is sometimes called the enhanced greenhouse effect. The change in a GHG concentration because of anthropogenic emissions contributes to an instantaneous radiative forcing. Earth's surface temperature and troposphere warm in response to this forcing, gradually restoring the radiative balance at the top of the atmosphere.

Heat index: A measure of how hot the air feels to the human body. The index is mainly based on surface air temperature and relative humidity, thus it reflects the combined effect of high temperature and humidity on human physiology and provides a relative indication of potential health risks.

Heatwave: A period of abnormally hot weather often defined with reference to a relative temperature threshold, lasting from two days to months. Heatwaves and warm spells have various and, in some cases, overlapping definitions.

Hot Extreme: A heat-related extreme event, when a value of a variable exceeds a heat-related threshold. For example, two sets of frequency of hot/warm days have been used in the literature. One counts the number of days when maximum daily temperature is above a relative threshold defined as the 90th or higher percentile of maximum daily temperature for the calendar day over a base period. The other counts the number of days in which maximum daily temperature is above an absolute threshold, such as 35°C. (Definition taken from Chapter 11 of the Working Group I Sixth Assessment Report)

Intergovernmental Panel on Climate Change (IPCC): The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. Created by the United Nations Environment Programme (UN Environment) and the World Meteorological Organization (WMO) in 1988, the IPCC has 195 Member countries. The IPCC comprises three Working Groups (WG) and a Taskforce for National Greenhouse Gas Inventories (TFI).

> **Working Group I (WGI)**: The IPCC Working Group I (WGI) The Physical Science Basis is the first of the three IPCC Working Groups (WGs). WGI examines the physical science underpinning past, present, and future climate change.
>
> **Working Group II (WGII)**: The IPCC Working Group II (WGII) Impacts, Adaptation and Vulnerability is the second of the three IPCC Working Groups (WGs). WGII assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change and options for adapting to it.

Working Group III (WGIII): The IPCC Working Group III (WGII) Mitigation is the third of the three IPCC Working Groups (WGs). WG III focuses on climate change mitigation, assessing methods for reducing greenhouse gas emissions, and removing greenhouse gases from the atmosphere.

The Task Force on National Greenhouse Gas Inventories (TFI): The Task Force on National Greenhouse Gas Inventories (TFI) develops and refines an internationally-agreed methodology and software for the calculation and reporting of national greenhouse gas emissions and removals and encourages the use of this methodology by countries participating in the IPCC and by signatories of the United Nations Framework Convention on Climate Change (UNFCCC).

Marine heatwave: A period during which water temperature is abnormally warm for the time of the year relative to historical temperatures, with that extreme warmth persisting for days to months. The phenomenon can manifest in any place in the ocean and at scales of up to thousands of kilometres.

Mitigation (of climate change): A human intervention to reduce emissions or enhance the sinks of greenhouse gases.

Non-carbon-dioxide emissions and radiative forcing: Non-carbon-dioxide emissions included in this report are all anthropogenic emissions other than carbon dioxide that result in radiative forcing. These include short-lived climate forcers, such as methane, some fluorinated gases, ozone precursors, aerosols or aerosol precursors, such as black carbon and sulphur dioxide, respectively, as well as long-lived greenhouse gases, such as nitrous oxide or other fluorinated gases. The radiative forcing associated with non-carbon-dioxide emissions and changes in surface albedo (e.g., resulting from land-use change) is referred to as non-carbon-dioxide radiative forcing.

Precursors: Atmospheric compounds that are not greenhouse gases or aerosols, but that have an effect on greenhouse gas or aerosol concentrations by taking part in physical or chemical processes regulating their production or destruction rates.

Pre-industrial (period): The multi-century period prior to the onset of large-scale industrial activity around 1750. The reference period 1850–1900 is used to approximate pre-industrial global mean surface temperature (GMST).

Radiative forcing: The change in the net, downward minus upward, radiative flux (expressed in W m–2) due to a change in an external driver of climate change, such as a change in the concentration of carbon dioxide, the concentration of volcanic aerosols or in the output of the Sun. The stratospherically adjusted radiative forcing is computed with all tropospheric properties held fixed at their unperturbed values, and after allowing for stratospheric temperatures, if perturbed, to readjust to radiative-dynamical equilibrium. Radiative forcing is called instantaneous if no change in stratospheric temperature is accounted for. The radiative forcing once both stratospheric and tropospheric adjustments are accounted for is termed the effective radiative forcing.

Reasons for concern (RFCs): Elements of a classification framework, first developed in the IPCC Third Assessment Report, which aims to facilitate judgments about what level of climate

change may be dangerous (in the language of Article 2 of the UNFCCC; UNFCCC, 1992) by aggregating risks from various sectors, considering hazards, exposures, vulnerabilities, capacities to adapt, and the resulting impacts.

Representative Concentration Pathways (RCPs): Representative Concentration Pathways (RCPs) usually refer to the portion of the concentration pathway extending up to 2100, for which integrated assessment models produced corresponding emission scenarios. Extended concentration pathways describe extensions of the RCPs from 2100 to 2300 that were calculated using simple rules generated by stakeholder consultations, and do not represent fully consistent scenarios. Four RCPs produced from integrated assessment models were selected from the published literature and used in the Fifth IPCC Assessment, and are also used in this Assessment for comparison, spanning the range from approximately below 2°C warming to high (>4°C) warming best-estimates by the end of the 21st century: RCP2.6, RCP4.5 and RCP6.0 and RCP8.5.

Shared Socio-economic Pathways (SSPs): Shared Socio-economic Pathways (SSPs) have been developed to complement the Representative Concentration Pathways (RCPs). By design, the RCP emission and concentration pathways were stripped of their association with a certain socioeconomic development. Different levels of emissions and climate change along the dimension of the RCPs can hence be explored against the backdrop of different socio-economic development pathways (SSPs) on the other dimension in a matrix. This integrative SSP-RCP framework is now widely used in the climate impact and policy analysis literature, where climate projections obtained under the RCP scenarios are analysed against the backdrop of various SSPs.

Short-lived climate forcers (SLCFs): A set of chemically reactive compounds with short (relative to carbon dioxide) atmospheric lifetimes (from hours to about two decades) but characterized by different physiochemical properties and environmental effects. Their emission or formation has a significant effect on radiative forcing over a period determined by their respective atmospheric lifetimes. Changes in their emissions can also induce long-term climate effects via, in particular, their interactions with some biogeochemical cycles. SLCFs are classified as direct or indirect, with direct SLCFs exerting climate effects through their radiative forcing and indirect SLCFs being the precursors of other direct climate forcers. Direct SLCFs include methane (CH4), ozone (O3), primary aerosols and some halogenated species. Indirect SLCFs are precursors of ozone or secondary aerosols. SLCFs can be cooling or warming through interactions with radiation and clouds. They are also referred to as near-term climate forcers. Many SLCFs are also air pollutants. A subset of exclusively warming SLCFs is also referred to as short-lived climate pollutants (SLCPs), including methane, ozone, and black carbon (BC).

Well mixed greenhouse gases: The well-mixed greenhouse gases have lifetimes long enough to be relatively homogeneously mixed in the troposphere.