Klimaänderung II

11. Extremereignisse bei Wetter und Klima in einem sich ändernden Klima

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Vorlesung SS 2022

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- http://www.pa.op.dlr.de/~RobertSausen/vorlesung/index.html
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  - Slides of the lecture (with some delay)
  - See also LSF https://lsf.verwaltung.uni-muenchen.de/
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Working Group I: the Physical Science Basis

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Chapter 11: Weather and Climate Extreme Events in a Changing Climate

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Chapter 11: Weather and Climate Extreme Events in a Changing Climate

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Süddeutsche Zeitung

Klima

Trump spottet über Klimawandel: "Mehr Grundstü-cke am Strand"

10. Juli 2022, 11:06 Uhr | Lesezeit: 1 min

Direkt aus dem dpa-Newskanal

Washington (dpa) - Der frühere US-Präsident Donald Trump hat sich spöttisch über die sich verschärfende Klimakrise geäußert. "Wir werden ein bisschen mehr Grundstücke am Strand haben, was nicht das Schlechteste auf der Welt ist", sagte er bei einem Wahlkampfauftritt in Anchorage im US-Bundesstaat Alaska.

"Ich habe gehört, dass die Ozeane in den nächsten 300 Jahren um ein Achtel Zoll (knapp 0,32 Zentimeter) ansteigen werden. Wir haben größere Probleme als das." In den USA stehen im November Kongresswahlen an.

Trump ließ auch bei seinem Wahlkampfauftritt in Alaska weiter offen, ob er bei der Präsidentenwahl 2024 erneut antreten will. Er kündigte lediglich an: "Wir werden unser prächtiges Weißes Haus zurückerobern." Trump wiederholte seine widerlegte Behauptung, wonach er bei der Wahl 2020 durch Betrug um seinen Sieg gebracht worden sei.

Trump hat wiederholt daran gezweifelt, ob der Klimawandel menschengemacht ist - solche Zweifel sind wissenschaftlich klar widerlegt. Der Republikaner hatte die USA während seiner Amtszeit aus dem Pariser Klimaschutzabkommen zurückgezogen. Sein demokratischer Nachfolger Joe Biden hatte den Schritt nach seinem Amtsantritt Anfang vergangenen Jahres umgehend rückgängig gemacht und die USA wieder zurück in das Abkommen geführt. Biden hat den Kampf gegen den Klimawandel zu einem seiner wichtigsten Ziele erklärt.

Trump erklärte bei seinem Auftritt in Alaska seine Unterstützung für die frühere Vizepräsidentschaftskandidatin Sarah Palin, die sich um einen Sitz im US-Repräsentantenhaus bewirbt. Trump rief die Wähler dazu auf, die "großartige, legendäre Palin" nach Washington zu schicken. Palin war im Wahlkampf 2008 zur Zielscheibe von Spott geworden, als sie als Vizepräsidentschaftskandidatin behauptet hatte, sie könne von ihrem Haus in Alaska aus Russland sehen.

Palin trat am Samstagabend kurz an der Seite Trumps auf. "Wir lieben Dich", sagte sie an die Adresse des Ex-Präsidenten. "Wir brauchen Dich zurück." Trump kündigte an, die Republikaner würden bei den Kongresswahlen die Mehrheit im Repräsentantenhaus zurückerobern. Mit Blick auf die demokratische Vorsitzende der Parlamentskammer, Nancy Pelosi, sagte der 76-jährige Republikaner: "Wir werden die politische Karriere der verrückten Nancy Pelosi ein für allemal beenden."

URL: www.sz.de/dpa.urn-newsml-dpa-com-20090101-220710-99-969987

Quelle: Direkt aus dem dpa-Newskanal

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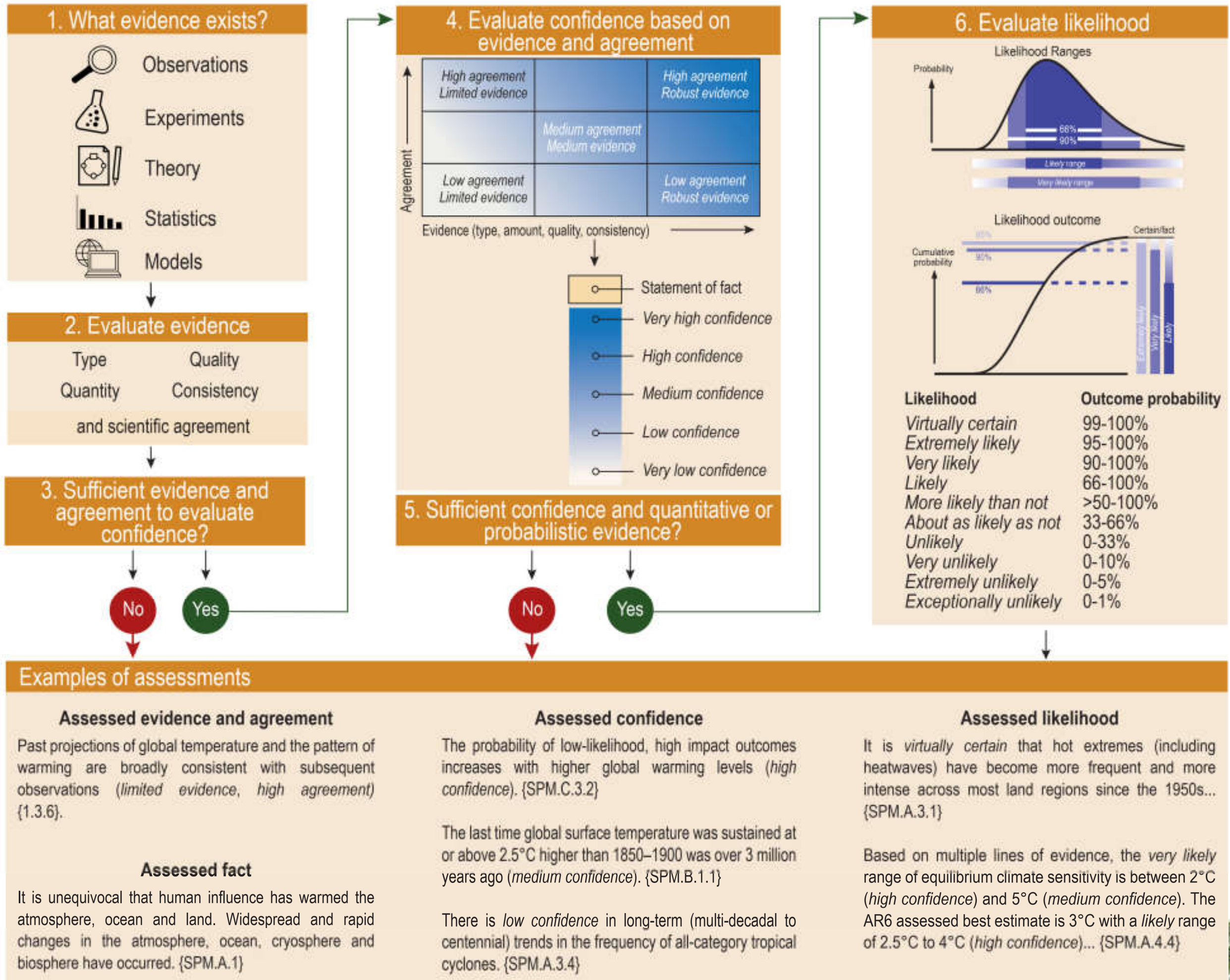
Evaluation and communication of degree of certainty in AR6 findings



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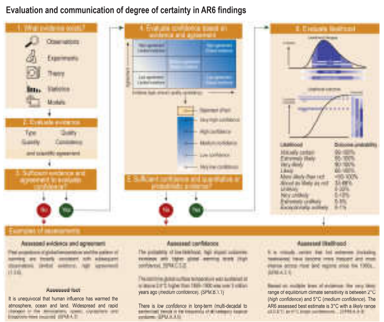

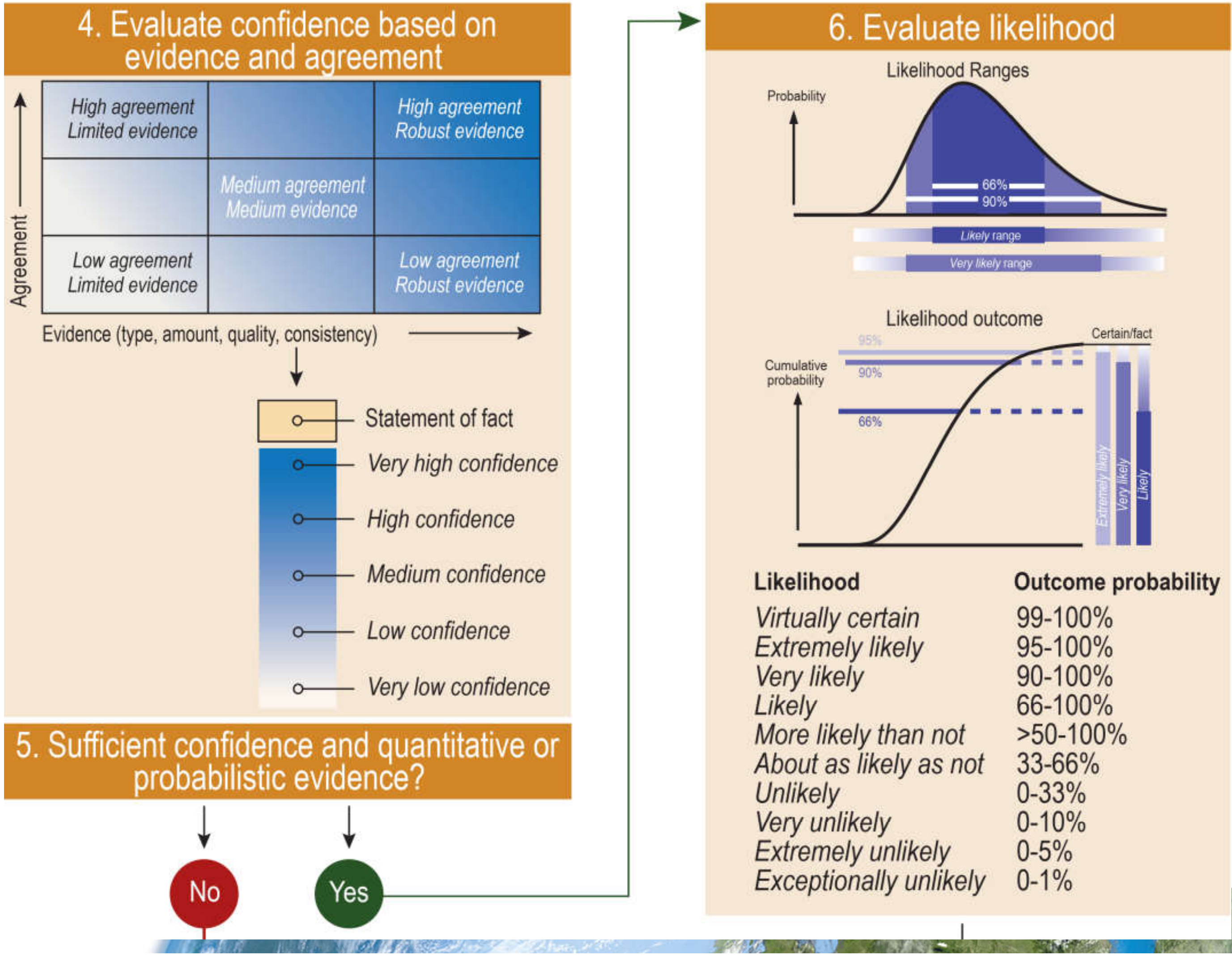

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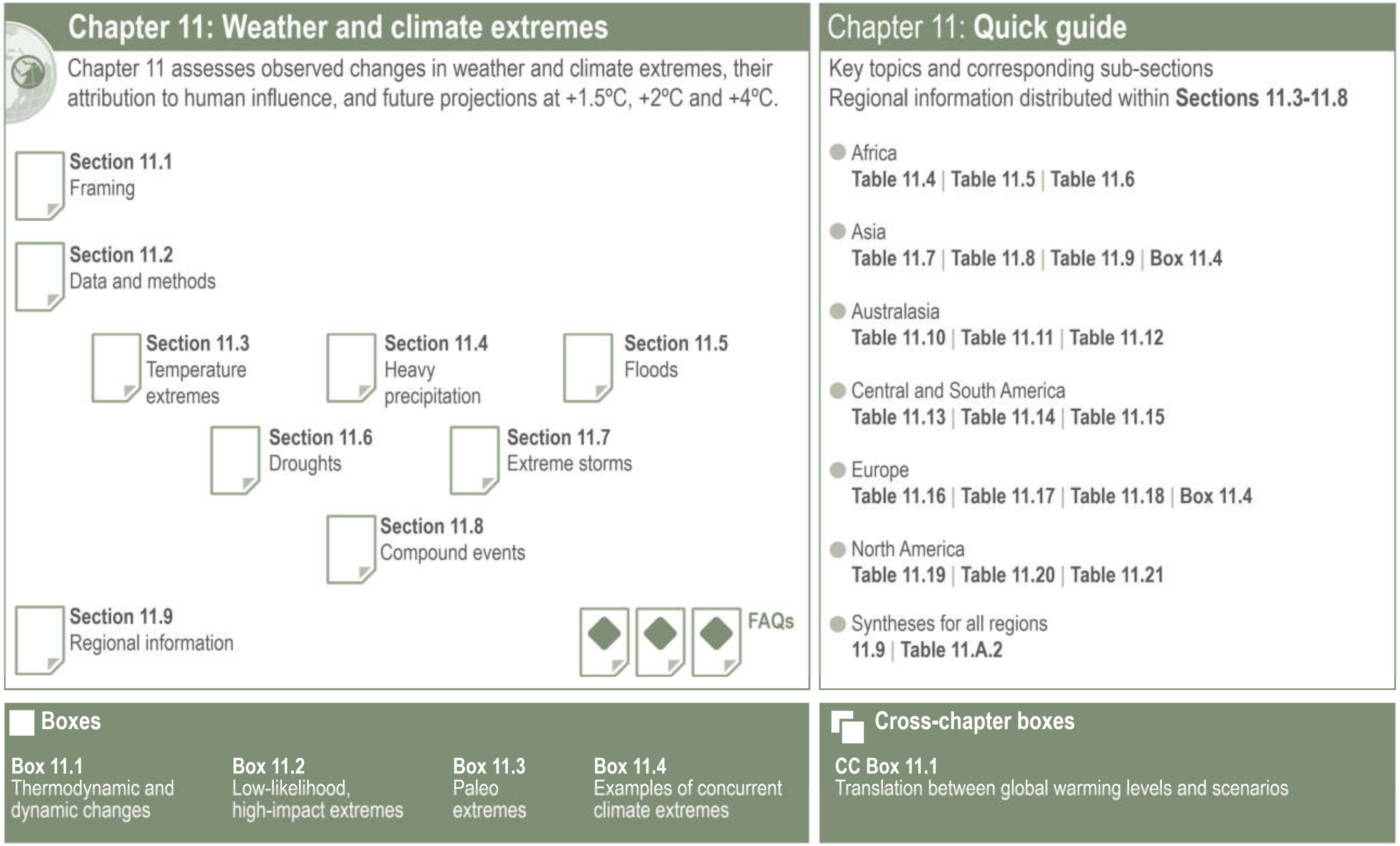

Figure 11.1 | Visual guide to Chapter 11.

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Statements in the Executive Summary

This chapter assesses changes in weather and climate extremes on regional and global scales, including observed changes and their attribution, as well as projected changes. The extremes considered include temperature extremes, heavy precipitation and pluvial floods, river floods, droughts, storms (including tropical cyclones), as well as compound events (multivariate and concurrent extremes). The assessment focuses on land regions excluding Antarctica. Changes in marine extremes are addressed in Chapter 9 and Cross-Chapter Box 9.1.

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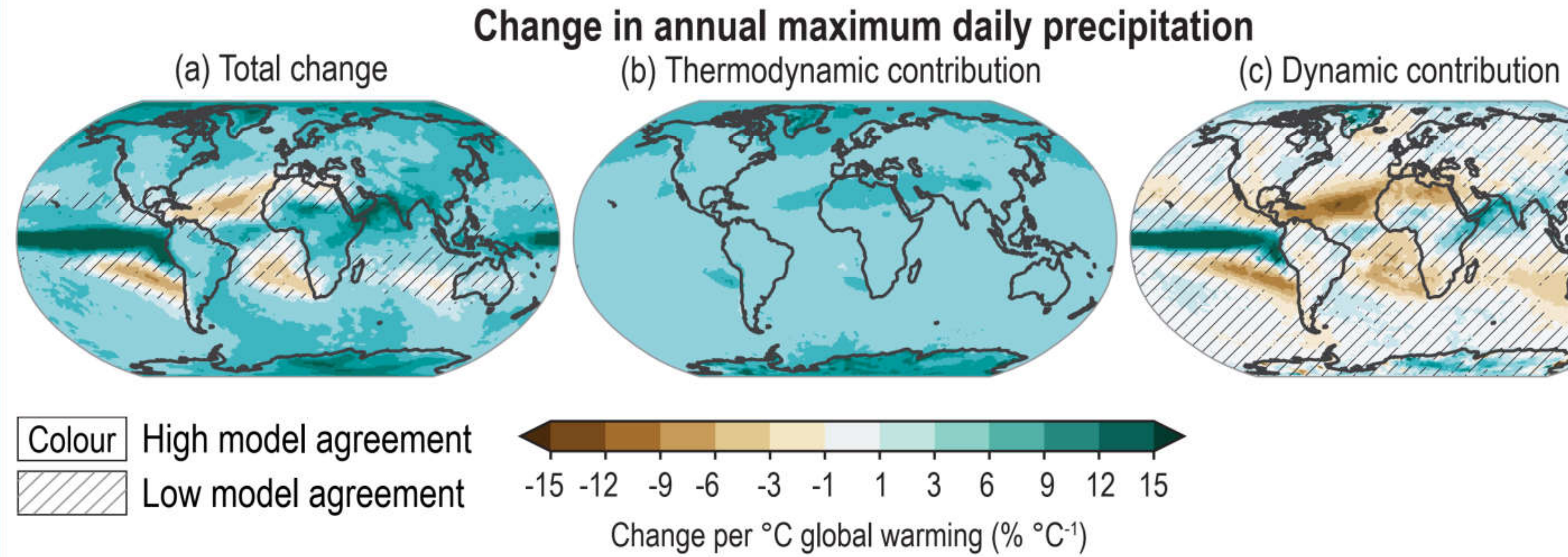
Multi-model Coupled Model Intercomparison Project Phase 5 (CMIP5) mean fractional changes (in % per degree of warming)



Box 11.1, Figure 1: Multi-model Coupled Model Intercomparison Project Phase 5 (CMIP5) mean fractional changes (in % per degree of warming). **(a)** changes in annual maximum precipitation (Rx1day); **(b)** changes in Rx1day due to the thermodynamic contribution; and **(c)** changes in Rx1day due to the dynamic contribution estimated as the difference between the total changes and the thermodynamic contribution. Changes were derived from a linear regression for the period 1950–2100. Uncertainty is represented using the simple approach: no overlay indicates regions with high model agreement, where ≥80% of models (n=22) agree on the sign of change; diagonal lines indicate regions with low model agreement, where <80% of models agree on the sign of change. For more information on the simple approach, please refer to the Cross-Chapter Box Atlas 1. A detailed description of the estimation of dynamic and thermodynamic contributions is given in Pfahl et al. (2017). Figure adapted from Pfahl et al. (2017), originally published in *Nature Climate Change/Springer Nature.* Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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This chapter assesses changes in weather and climate extremes on regional and global scales, including observed changes and their attribution, as well as projected changes. The extremes considered include temperature extremes, heavy precipitation and pluvial floods, river floods, droughts, storms (including tropical cyclones), as well as compound events (multivariate and concurrent extremes). The assessment focuses on land regions excluding Antarctica. Changes in marine extremes are addressed in Chapter 9 and Cross-Chapter Box 9.1. Assessments of past changes and their drivers are from 1950 onward, unless indicated otherwise. Projections for changes in extremes are presented for different levels of global warming, supplemented with information for the conversion to emissions scenario-based projections (CrossChapter Box 11.1 and Table 4.2).

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It is an established fact that human-induced greenhouse gas emissions have led to an increased frequency and/or intensity of some weather and climate extremes since pre-industrial time, in particular for temperature extremes. Evidence of observed changes in extremes and their attribution to human influence (including greenhouse gas and aerosol emissions and land-use changes) has strengthened since AR5, in particular for extreme precipitation, droughts, tropical cyclones and compound extremes (including dry/hot events and fire weather). Some recent hot extreme events would have been *extremely unlikely* to occur without human influence on the climate system. {11.2, 11.3, 11.4, 11.6, 11.7, 11.8}

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Regional changes in the intensity and frequency of climate extremes generally scale with global warming. New evidence strengthens the conclusion from the IPCC Special Report on Global Warming of 1.5°C (SR1.5) that even relatively small incremental increases in global warming (+0.5°C) cause statistically significant changes in extremes on the global scale and for large regions (*high confidence*).

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Statements in the Executive Summary

Methods and Data for Extremes

Since AR5, the confidence about past and future changes in weather and climate extremes has increased due to better physical understanding of processes, an increasing proportion of the scientific literature combining different lines of evidence, and improved accessibility to different types of climate models (*high confidence*). There have been improvements in some observation-based datasets, including reanalysis data (*high confidence*). Climate models can reproduce the sign (direction) of changes in temperature extremes observed globally and in most regions, although the magnitude of the trends may differ (*high confidence*).

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Methods and Data for Extremes

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Temperature Extremes (1)

The frequency and intensity of hot extremes (including heatwaves) have increased, and those of cold extremes have decreased on the global scale since 1950 (*virtually certain*). This also applies at regional scale, with more than 80% of AR6 regions showing similar changes assessed to be at least *likely*. In a few regions, limited evidence (data or literature) prevents the reliable estimation of trends. {11.3, 11.9}

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Main region types used in IPCC AR6 WG 1

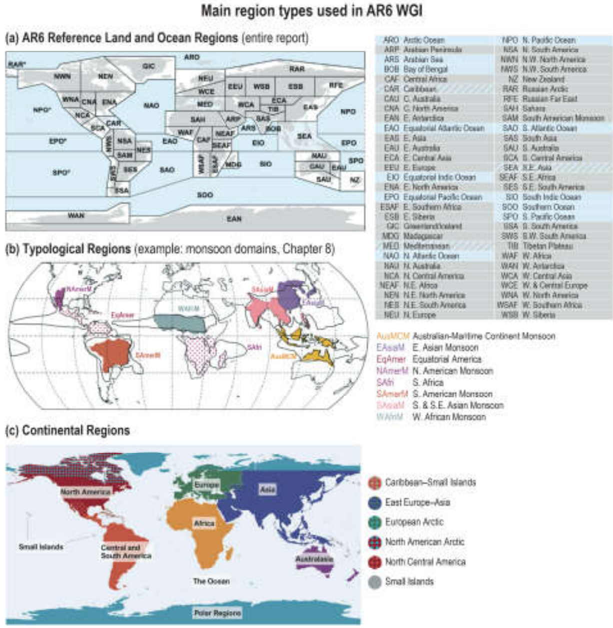

Figure 1.18 | Main region types used in this report. (a) AR6 WGI Reference Set of Land and Ocean Regions (Iturbide et al., 2020), consisting of 46 land regions and 15 ocean regions, including 3 hybrid regions (CAR, MED, SEA) that are both land and ocean regions. Abbreviations are explained to the right of the map. Notice that RAR, SPO, NPO and EPO extend beyond the 180° meridian, therefore appearing at both sides of the map (indicated by dashed lines). A comparison with the previous reference regions of AR5 WGI (IPCC, 2013a) is presented in the Atlas. **(b)** Example of typological regions: monsoon domains (see Chapter 8). Abbreviations are explained to the right of the map. The black contour lines represent the global monsoon zones, while the coloured regions denote the regional monsoon domains. The two stippled regions (EqAmer and SAfri) do receive seasonal rainfall, but their classification as monsoon regions is still under discussion. **(c)** Continental Regions used mainly in Chapter 12 and the Atlas. Stippled zones define areas that are assessed in both regions (e.g., the Caribbean is assessed as Small Islands and also as part of Central America). Small Islands are ocean regions containing small islands with consistent climate signals and/or climatological coherence.

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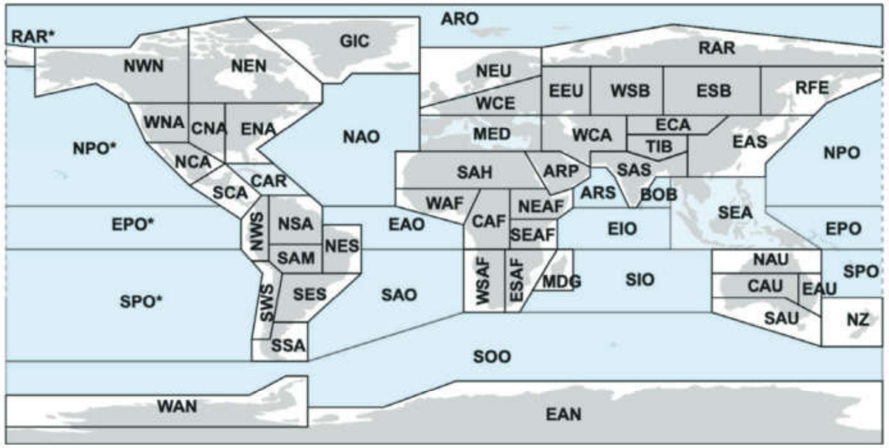
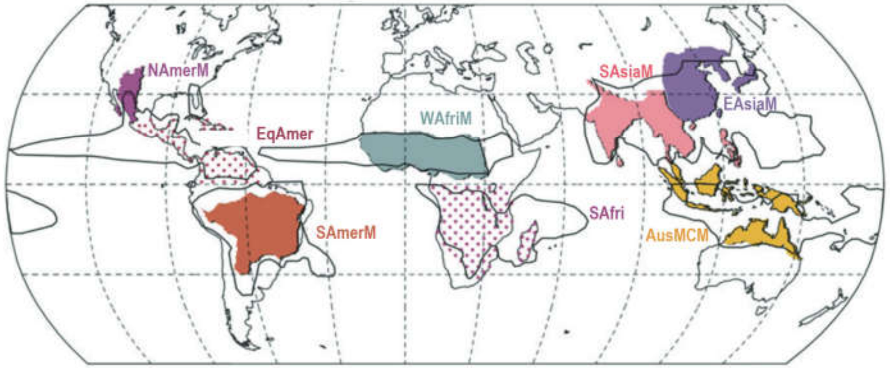
Main region types used in AR6 WGI

(a) AR6 Reference Land and Ocean Regions (entire report)



(b) Typological Regions (example: monsoon domains, Chapter 8)



ARO	Arctic Ocean	NPO	N. Pacific Ocean
ARP	Arabian Peninsula	NSA	N. South America
ARS	Arabian Sea	NWN	N.W. North America
BOB	Bay of Bengal	NWS	N.W. South America
CAF	Central Africa	NZ	New Zealand
CAR	Caribbean	RAR	Russian Arctic
CAU	C. Australia	RFE	Russian Far East
CNA	C. North America	SAH	Sahara
EAN	E. Antarctica	SAM	South American Monsoon
EAO	Equatorial Atlantic Ocean	SAO	S. Atlantic Ocean
EAS	E. Asia	SAS	South Asia
EAU	E. Australia	SAU	S. Australia
ECA	E. Central Asia	SCA	S. Central America
EEU	E. Europe	SEA	S.E. Asia
EIO	Equatorial Indic Ocean	SEAF	S.E. Africa
ENA	E. North America	SES	S.E. South America
EPO	Equatorial Pacific Ocean	SIO	South Indic Ocean
ESAF	E. Southern Africa	SOO	Southern Ocean
ESB	E. Siberia	SPO	S. Pacific Ocean
GIC	Greenland/Iceland	SSA	S. South America
MDG	Madagascar	SWS	S.W. South America
MED	Mediterranean	TIB	Tibetan Plateau
NAO	N. Atlantic Ocean	WAF	W. Africa
NAU	N. Australia	WAN	W. Antarctica
NCA	N. Central America	WCA	W. Central Asia
NEAF	N.E. Africa	WCE	W. & Central Europe
NEN	N.E. North America	WNA	W. North America
NES	N.E. South America	WSAF	W. Southern Africa
NEU	N. Europe	WSB	W. Siberia

AusMCM Australian-Maritime Continent Monsoon
EAsiaM E. Asian Monsoon
EqAmer Equatorial America
NAmerM N. American Monsoon
SAfri S. Africa
SAmerM S. American Monsoon
SAsiaM S. & S.E. Asian Monsoon
WAfriM W. African Monsoon

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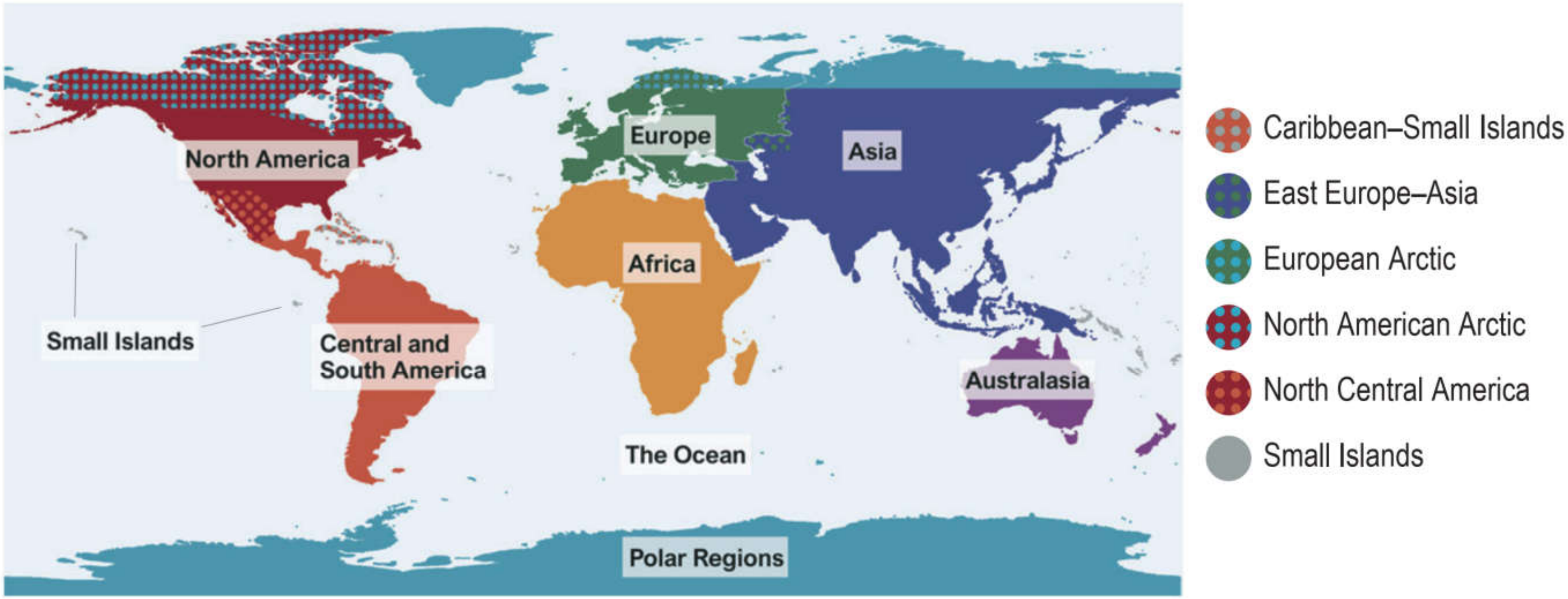
(c) Continental Regions



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Temperature Extremes (2)

Human-induced greenhouse gas forcing is the main driver of the observed changes in hot and cold extremes on the global scale (*virtually certain*) and on most continents (*very likely*). The effect of enhanced greenhouse gas concentrations on extreme temperatures is moderated or amplified at the regional scale by regional processes such as soil moisture or snow/ice-albedo feedbacks, by regional forcing from land-use and land-cover changes, or aerosol concentrations, and decadal and multi-decadal natural variability. Changes in anthropogenic aerosol concentrations have *likely* affected trends in hot extremes in some regions. Irrigation and crop expansion have attenuated increases in summer hot extremes in some regions, such as the Midwestern USA (*medium confidence*). Urbanization has likely exacerbated changes in temperature extremes in cities, in particular for nighttime extremes. {11.1, 11.2, 11.3}

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Time series of observed temperature anomalies

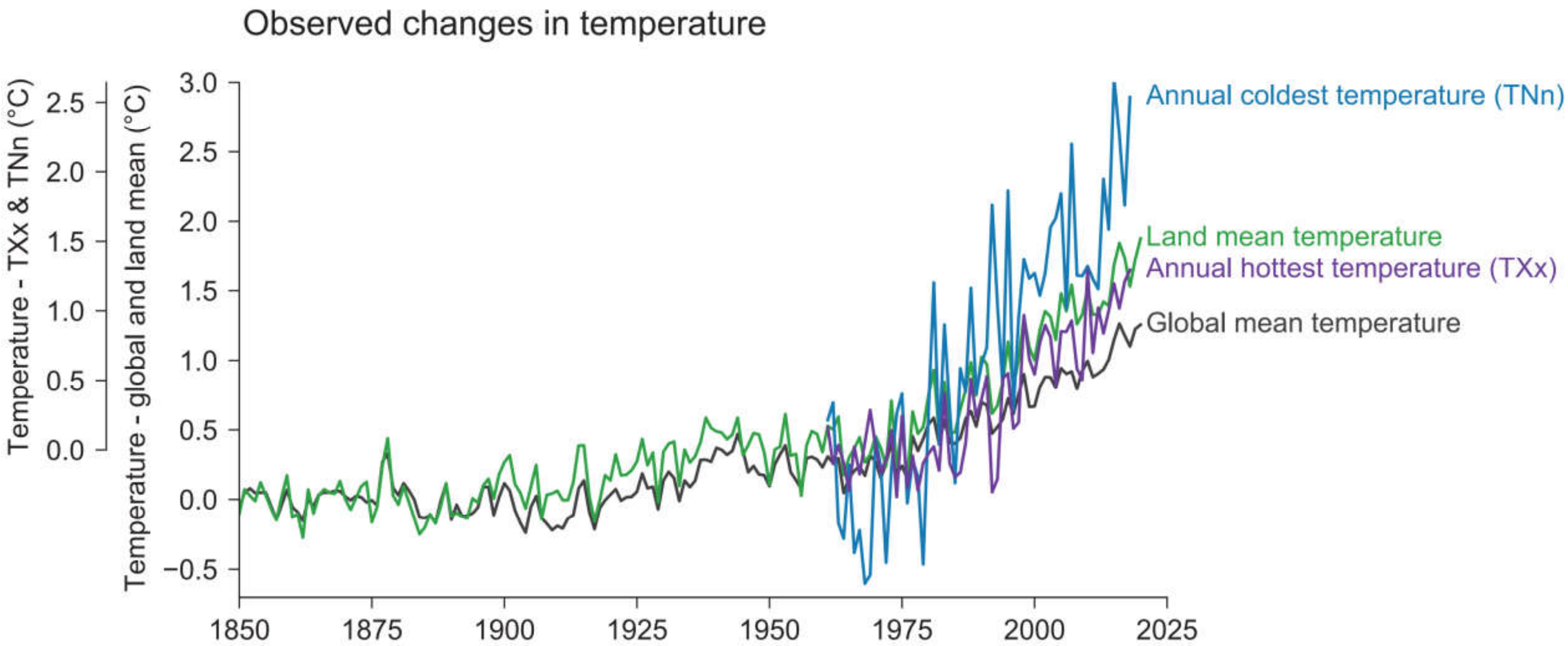

Figure 11.2 | Time series of observed temperature anomalies for global average annual mean temperature (black), land average annual mean temperature (green), land average annual hottest daily maximum temperature (TXx, purple), and land average annual coldest daily minimum temperature (TNn, blue). Global and land mean temperature anomalies are relative to their 1850–1900 means and are based on the multi-product mean annual time series assessed in Section 2.3.1.1.3 (see text for references). TXx and TNn anomalies are relative to their respective 1961–1990 means and are based on the HadEX3 dataset (Dunn et al., 2020) using values for grid boxes with at least 90% temporal completeness over 1961–2018. Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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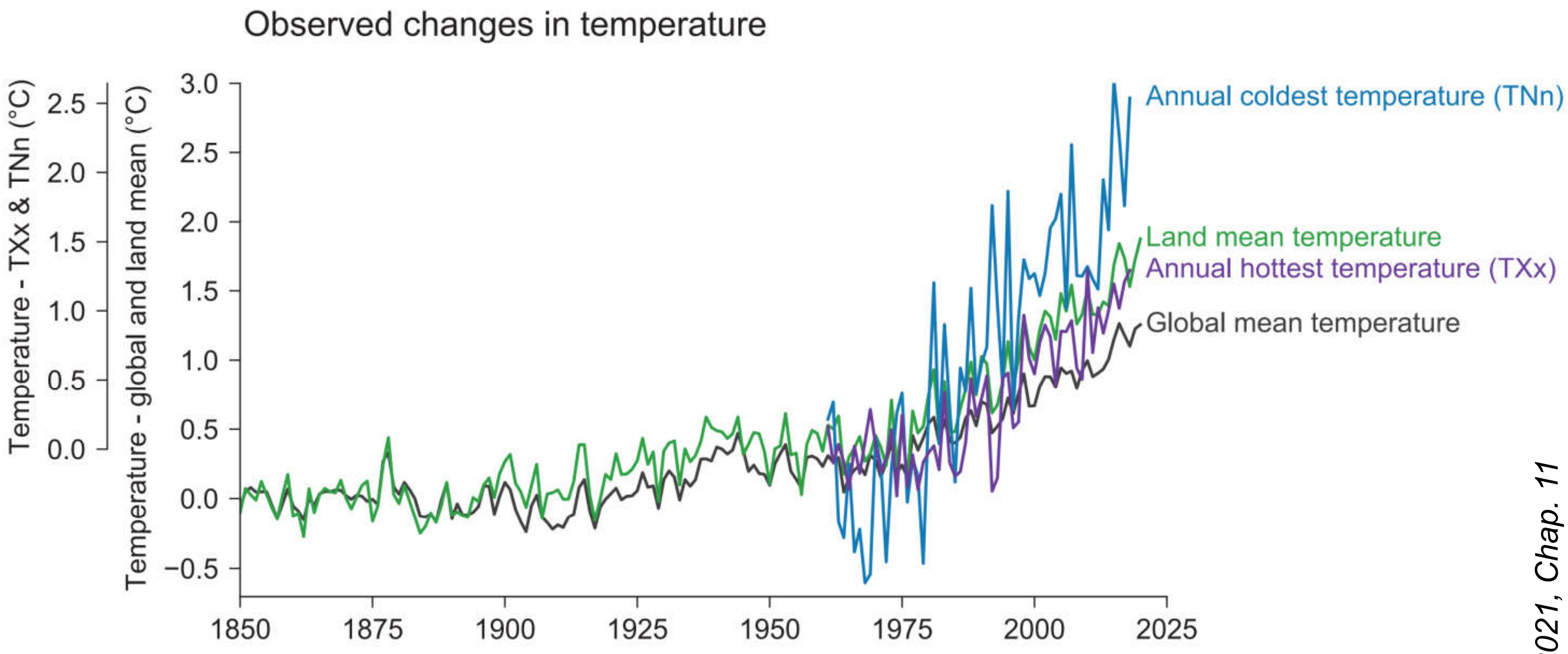

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Temperature Extremes (3)

The frequency and intensity of hot extremes will continue to increase and those of cold extremes will continue to decrease, at global and continental scales and in nearly all inhabited regions with increasing global warming levels. This will be the case even if global warming is stabilized at 1.5^{o}C. Relative to present-day conditions, changes in the intensity of extremes would be at least double at 2^{o}C, and quadruple at 3^{o}C of global warming, compared to changes at 1.5^{o}C of global warming. The number of hot days and hot nights and the length, frequency, and/or intensity of warm spells or heatwaves will increase over most land areas (*virtually certain*).

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Temperature Extremes (3)

The frequency and intensity of hot extremes will continue to increase and those of cold extremes will continue to decrease, at global and continental scales and in nearly all inhabited regions with increasing global warming levels. This will be the case even if global warming is stabilized at 1.5°C. Relative to present-day conditions, changes in the intensity of extremes would be at least double at 2°C, and quadruple at 3°C of global warming, compared to changes at 1.5°C of global warming. The number of hot days and hot nights and the length, frequency, and/or intensity of warm spells or heatwaves will increase over most land areas (*virtually certain*). In most regions, future changes in the intensity of temperature extremes will *very likely* be proportional to changes in global warming, and up to two to three times larger (*high confidence*). The highest increase of temperature of hottest days is projected in some mid-latitude and semi-arid regions and in the South American Monsoon region, at about 1.5 times to twice the rate of global warming (*high confidence*). The highest increase of temperature of coldest days is projected in Arctic regions, at about three times the rate of global warming (*high confidence*). The frequency of hot temperature extreme events will *very likely* increase nonlinearly with increasing global warming, with larger percentage increases for rarer events. {11.2, 11.3, 11.9; Table 11.1; Figure 11.3}

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Regional mean changes in annual hottest daily maximum temperature (TXx) for AR6 land regions and the global land area

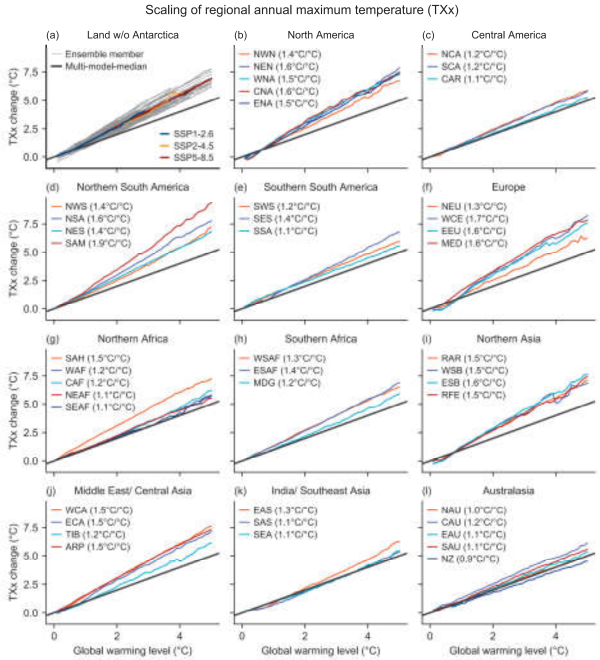

Figure 11.3 | Regional mean changes in annual hottest daily maximum temperature (TXx) for AR6 land regions and the global land area (except Antarctica), against changes in global mean surface air temperature (GSAT) as simulated by Coupled Model Intercomparison Project Phase 6 (CMIP6) models under different Shared Socio-economic Pathway (SSP) forcing scenarios, SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. Changes in TXx and GSAT are relative to the 1850–1900 baseline, and changes in GSAT are expressed as global warming level. **(a)** Individual models from the CMIP6 ensemble (grey), the multi-model median under three selected SSPs (colours), and the multi-model median (black); **(b) to (l)** Multi-model median for the pooled data for individual AR6 regions. Numbers in parentheses indicate the linear scaling between regional TXx and GSAT. The black line indicates the 1:1 reference scaling between TXx and GSAT. See Atlas.1.3.2 for the definition of regions. Changes in TXx are also displayed in the Interactive Atlas. For details on the methods, see Supplementary Material 11.SM.2.

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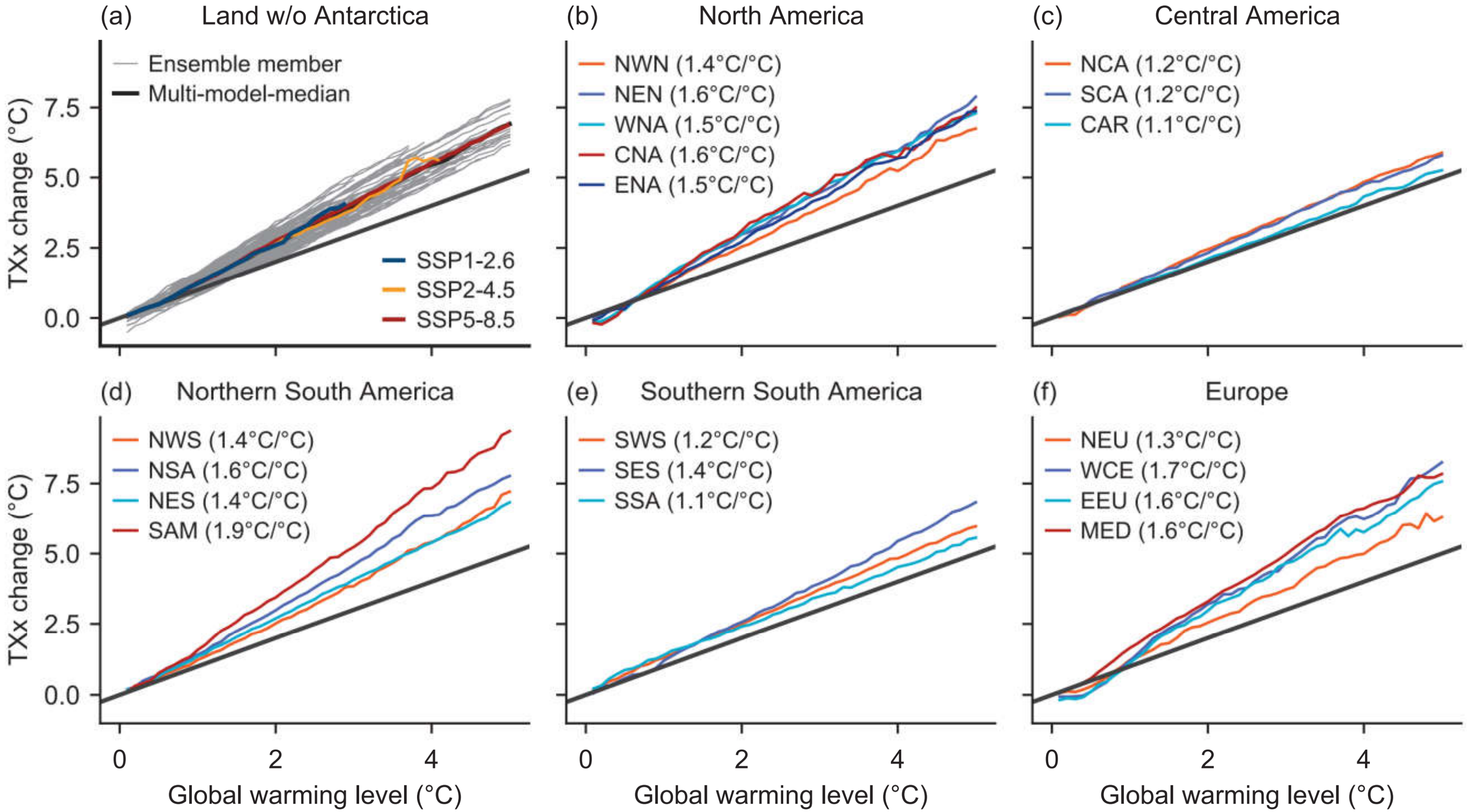
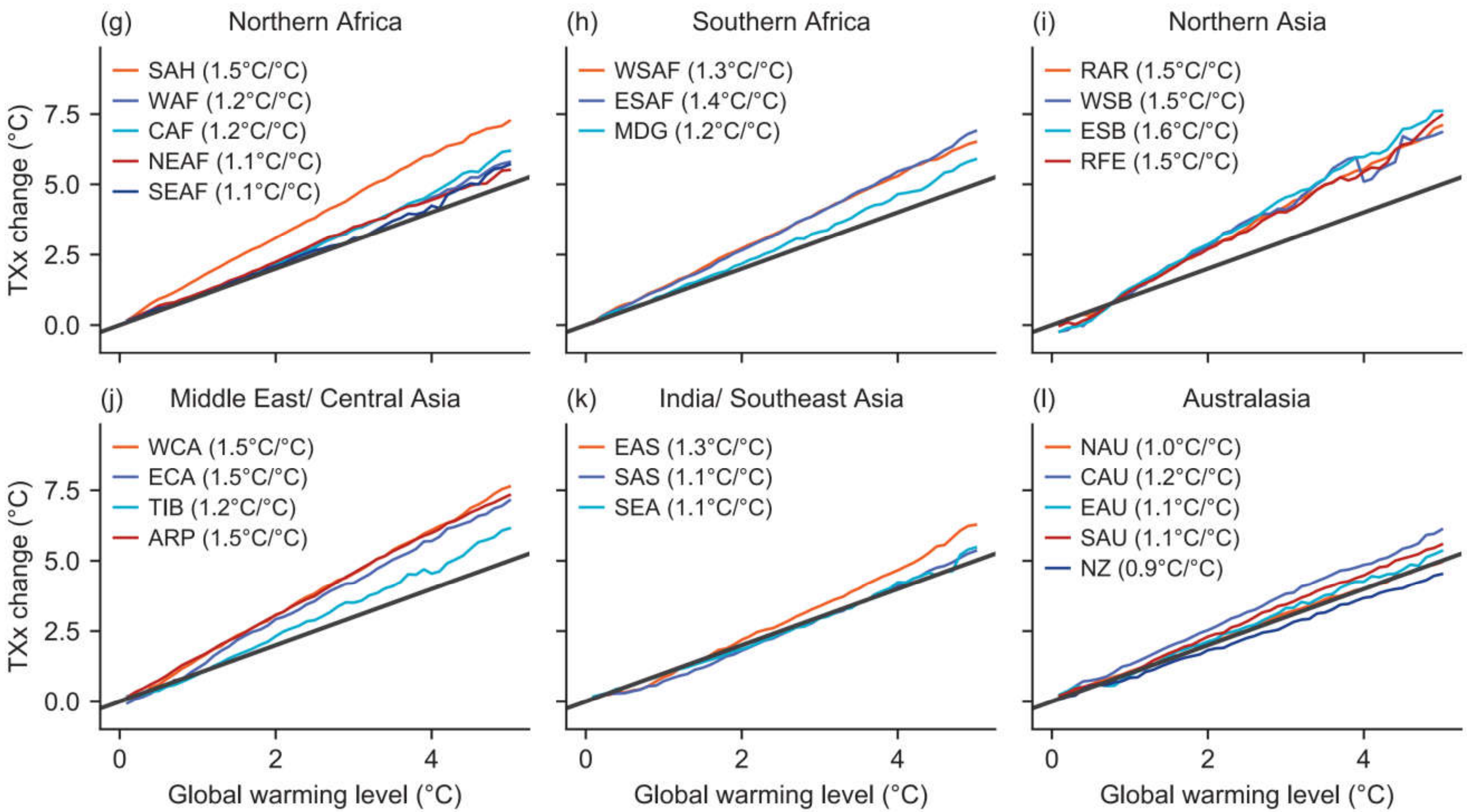
Scaling of regional annual maximum temperature (TXx)



IPCC 2021, Chap. 11

Scaling of regional annual maximum temperature (TXx)



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Observed changes for cold, hot and wet extremes and their potential human contribution

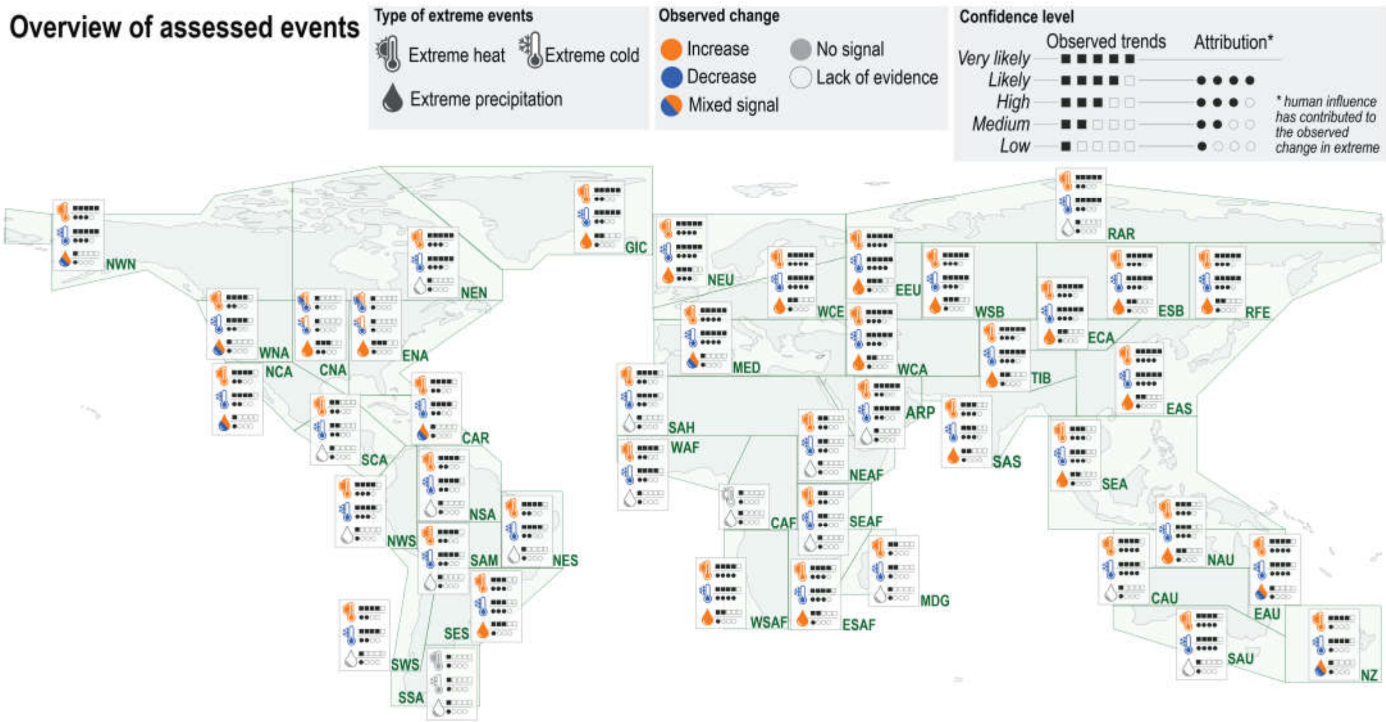

Figure 11.4 | Overview of observed changes for cold, hot, and wet extremes and their potential human contribution. Shown are the direction of change and the confidence in: 1) the observed changes in cold and hot as well as wet extremes across the world; and 2) whether human-induced climate change contributed to causing these changes (attribution). In each region changes in extremes are indicated by colour (orange – increase in the type of extreme; blue – decrease; both colours – changes of opposing direction within the region, with the signal depending on the exact event definition; grey – there are no changes observed; and no fill – the data/evidence is too sparse to make an assessment). The squares and dots next to the symbol indicate the level of confidence for observing the trend and the human contribution, respectively. The more black dots/squares, the higher the level of confidence. The information on this figure is based on regional assessment of the literature on observed trends, detection and attribution and event attribution in Section 11.9.

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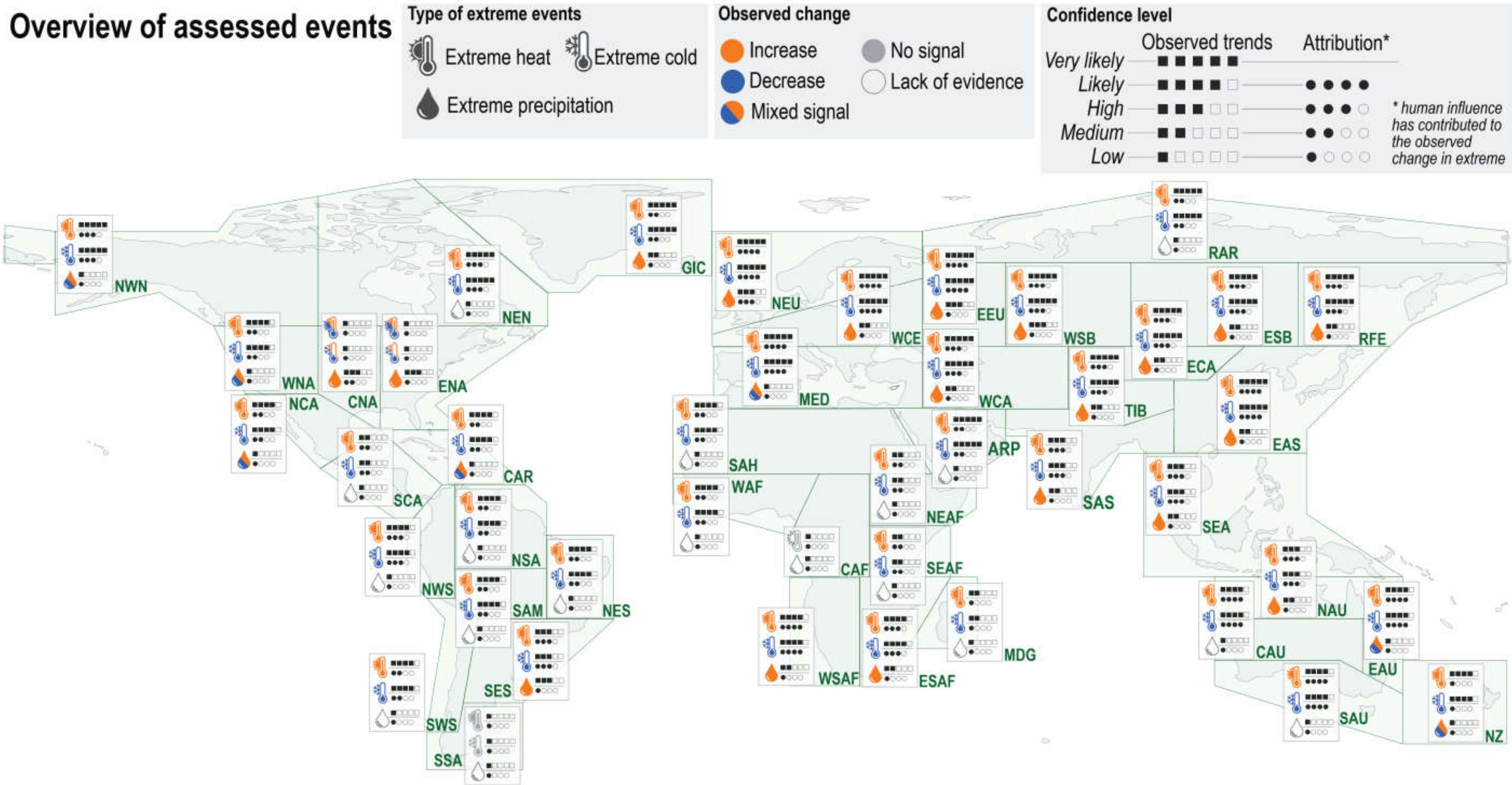
Sausen, Klimaänderung 2.11

Overview of assessed events



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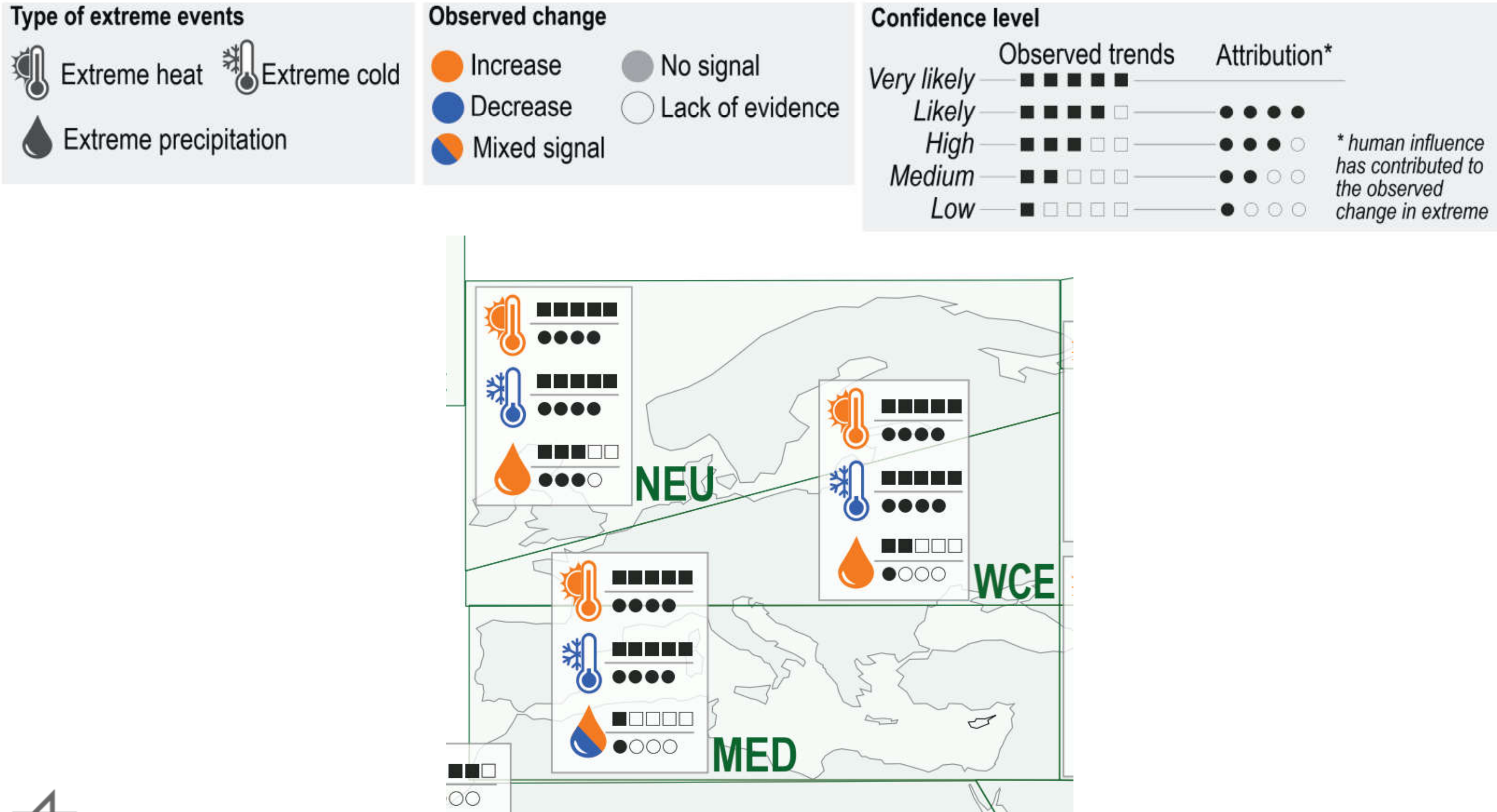

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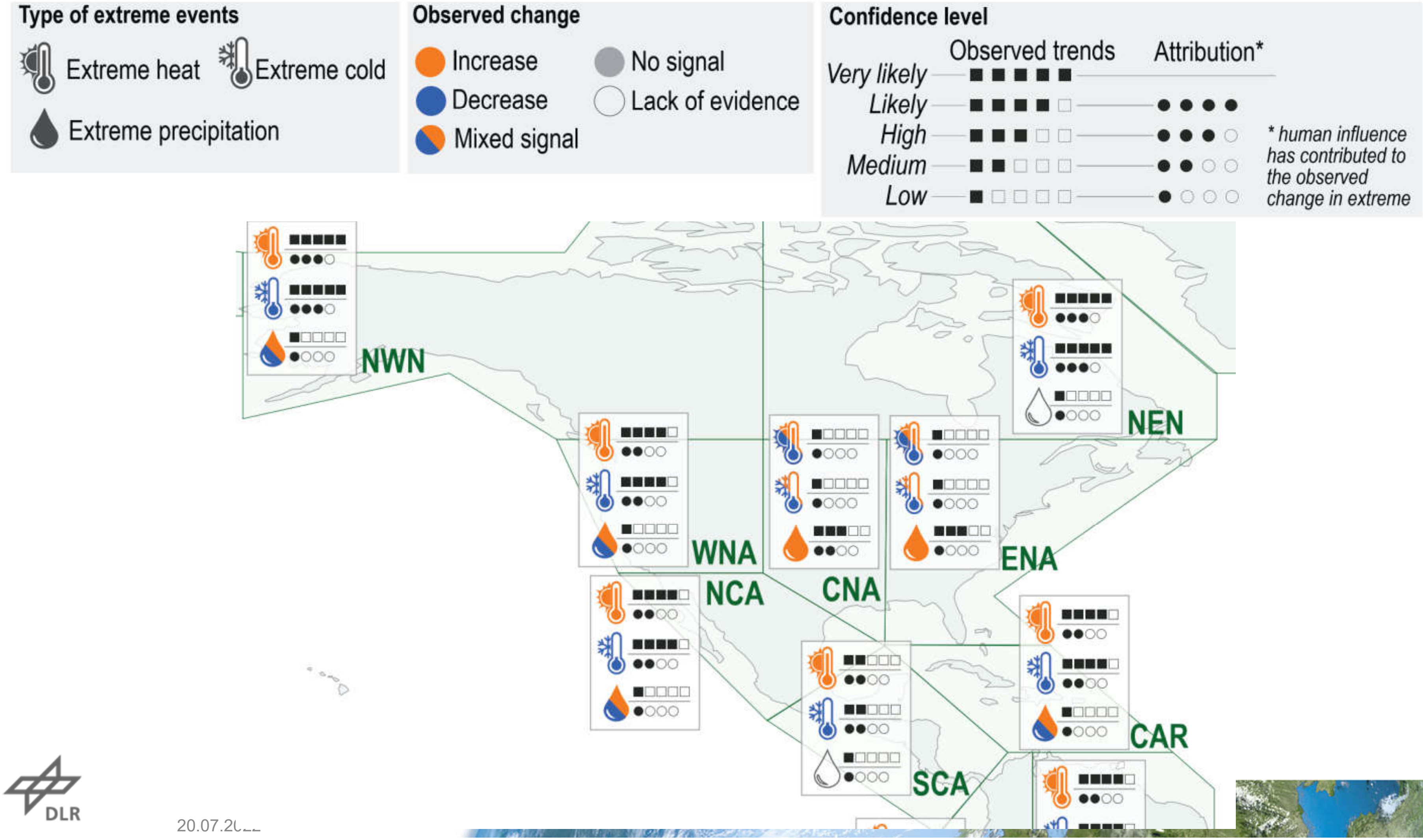

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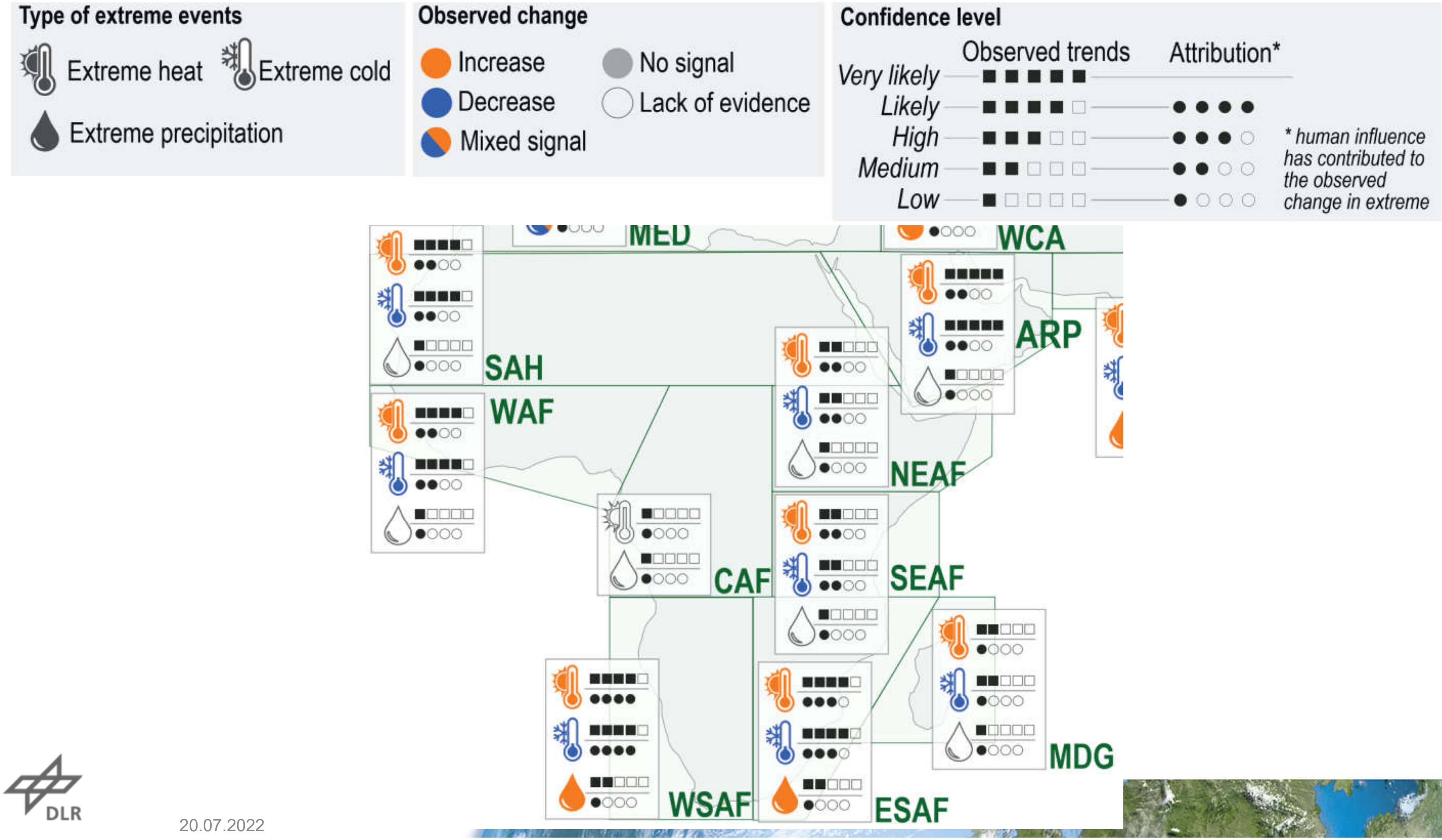

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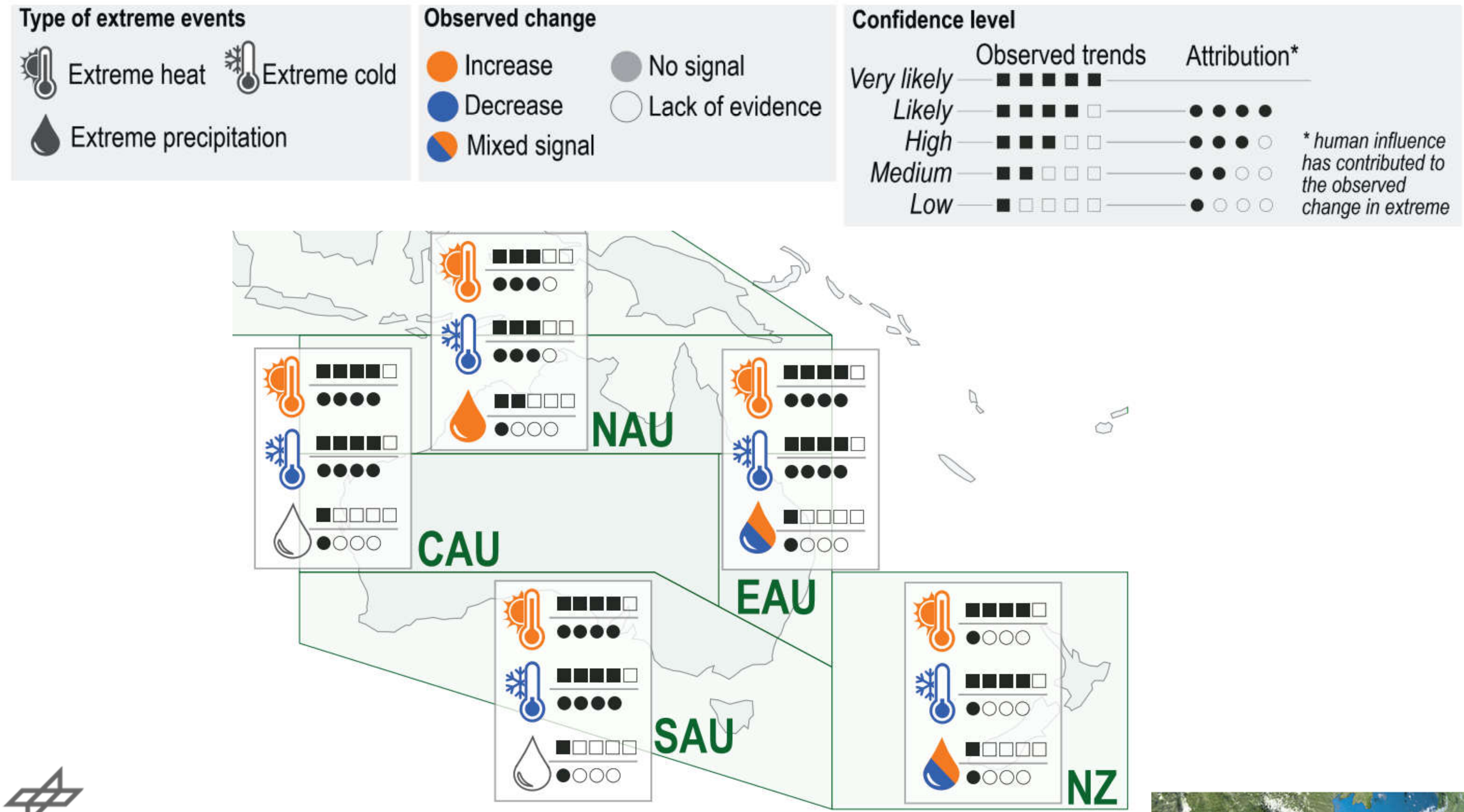

IPCC 2021, Chap. 11

Confidence and likelihood of past changes and projected future changes at 2°C of global warming on the global scale

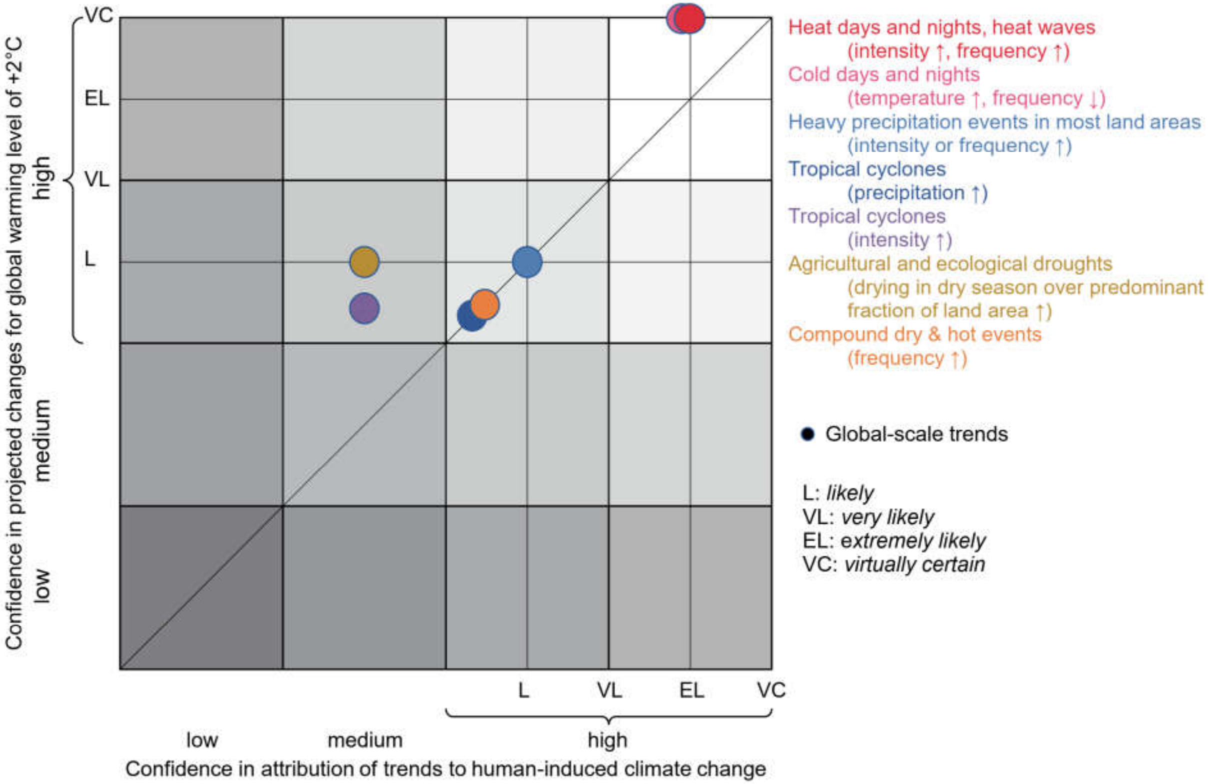

Figure 11.5 | Confidence and likelihood of past changes and projected future changes at 2°C of global warming on the global scale. The information in this figure is based on Tables 11.1 and 11.2.

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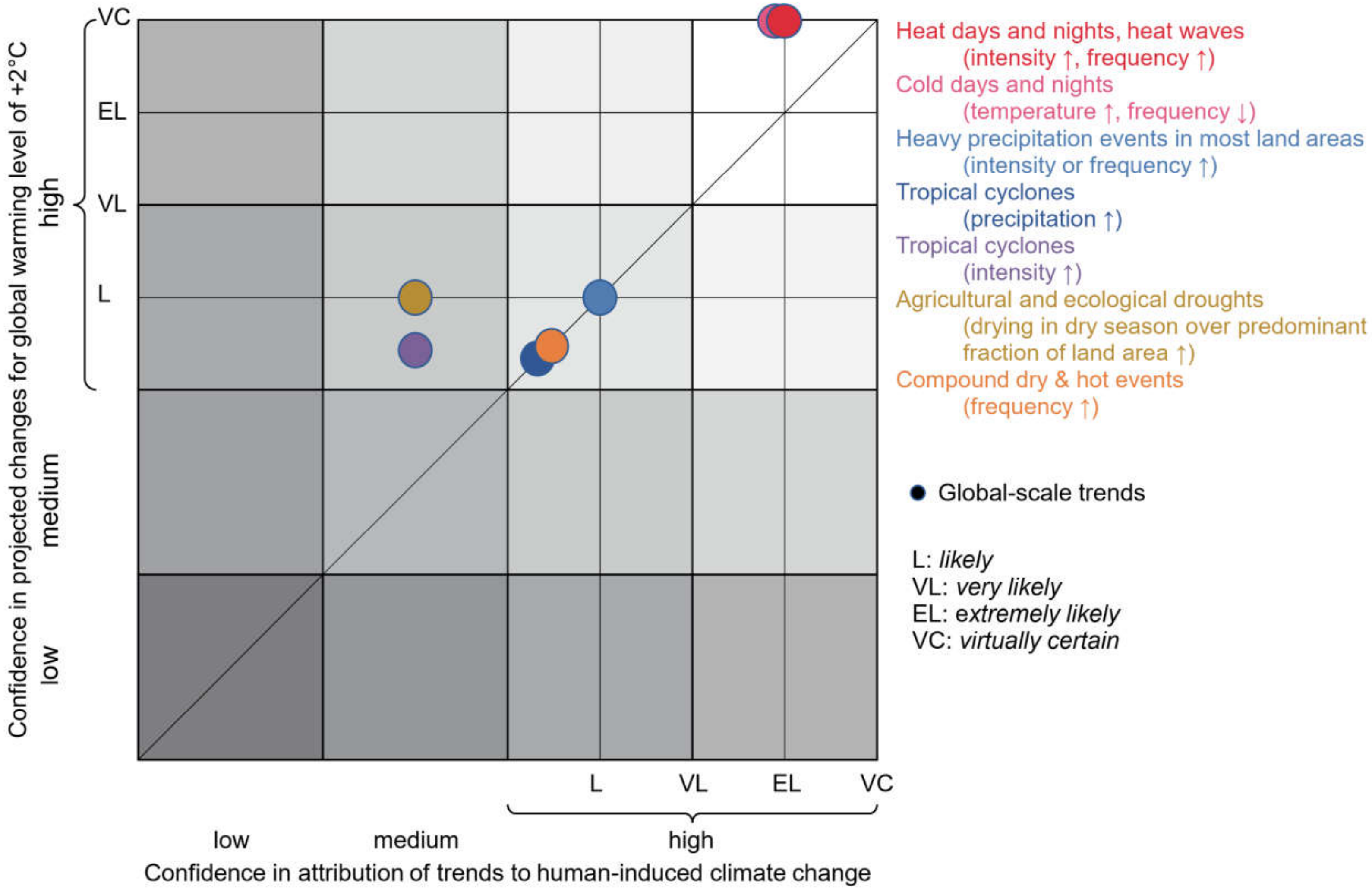

IPCC 2021, Chap. 11

Linear trends over 1960–2018 for three temperature extreme indices

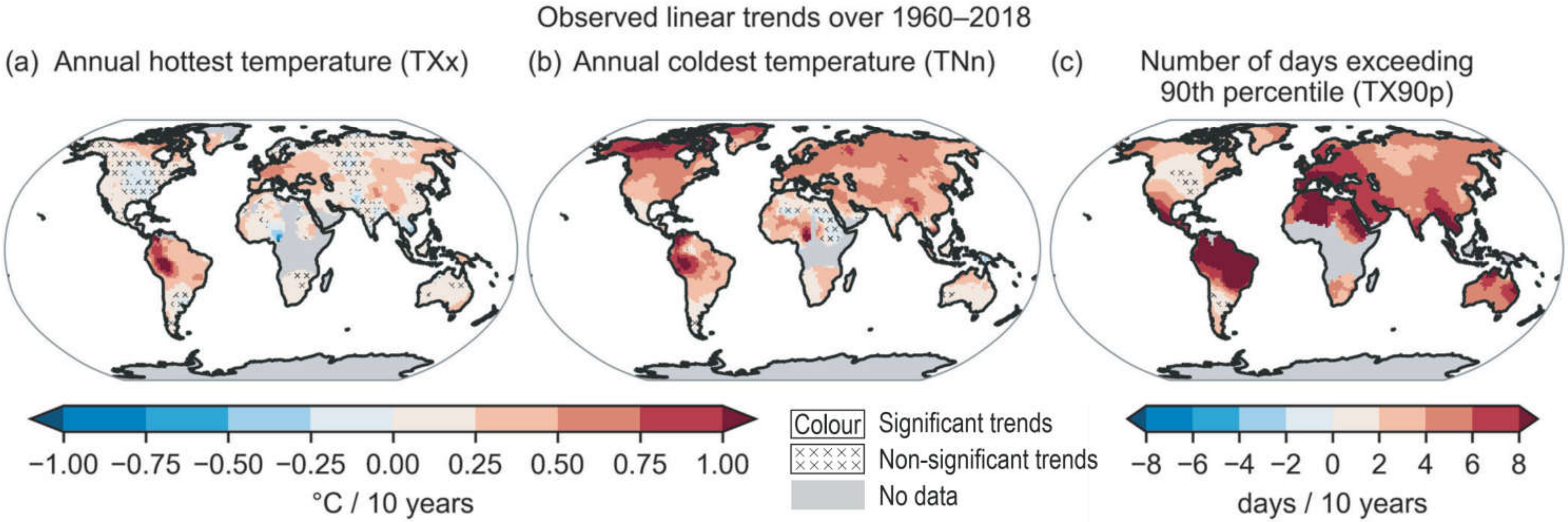

Figure 11.9 | Linear trends over 1960–2018 for three temperature extreme indices: (a) the annual maximum daily maximum temperature (TXx), **(b)** the annual minimum daily minimum temperature (TNn), and **(c)** the annual number of days when daily maximum temperature exceeds its 90th percentile from a base period of 1961–1990 (TX90p); based on the HadEX3 dataset (Dunn et al., 2020). Linear trends are calculated only for grid points with at least 66% of the annual values over the period and which extend to at least 2009. Areas without sufficient data are shown in grey. No overlay indicates regions where the trends are significant at the p = 0.1 level. Crosses indicate regions where trends are not significant. Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

IPCC 2021

Projected changes in annual maximum temperature (TXx) and annual minimum temperature (TNn)

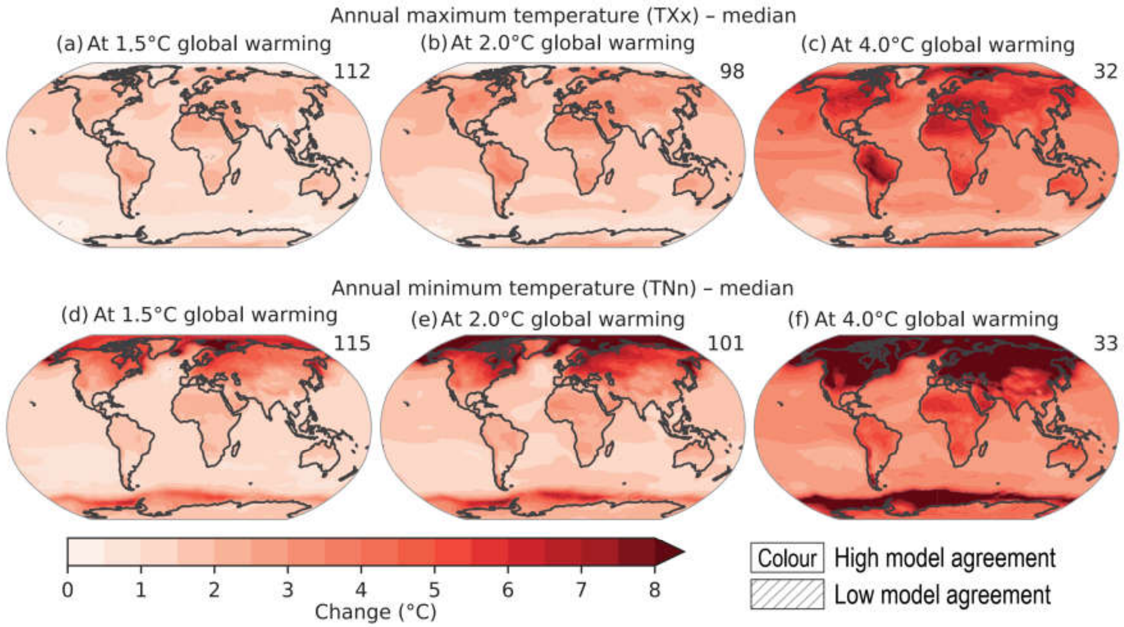

Figure 11.11 | Projected changes in (a–c) annual maximum temperature (TXx) and (d–f) annual minimum temperature (TNn) at 1.5°C, 2°C, and 4°C of global warming compared to the 1850–1900 baseline. Results are based on simulations from the Coupled Model Intercomparison Project Phase 6 (CMIP6) multi-model ensemble under the Shared Socio-economic Pathways (SSPs) SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios. The numbers in the top right indicate the number of simulations included. Uncertainty is represented using the simple approach: no overlay indicates regions with high model agreement, where ≥80% of models agree on the sign of change; diagonal lines indicate regions with low model agreement, where <80% of models agree on the sign of change. For more information on the simple approach, please refer to the Cross-Chapter Box Atlas 1. For details on the methods see Supplementary Material 11.SM.2. Changes in TXx and TNn are also displayed in the Interactive Atlas. Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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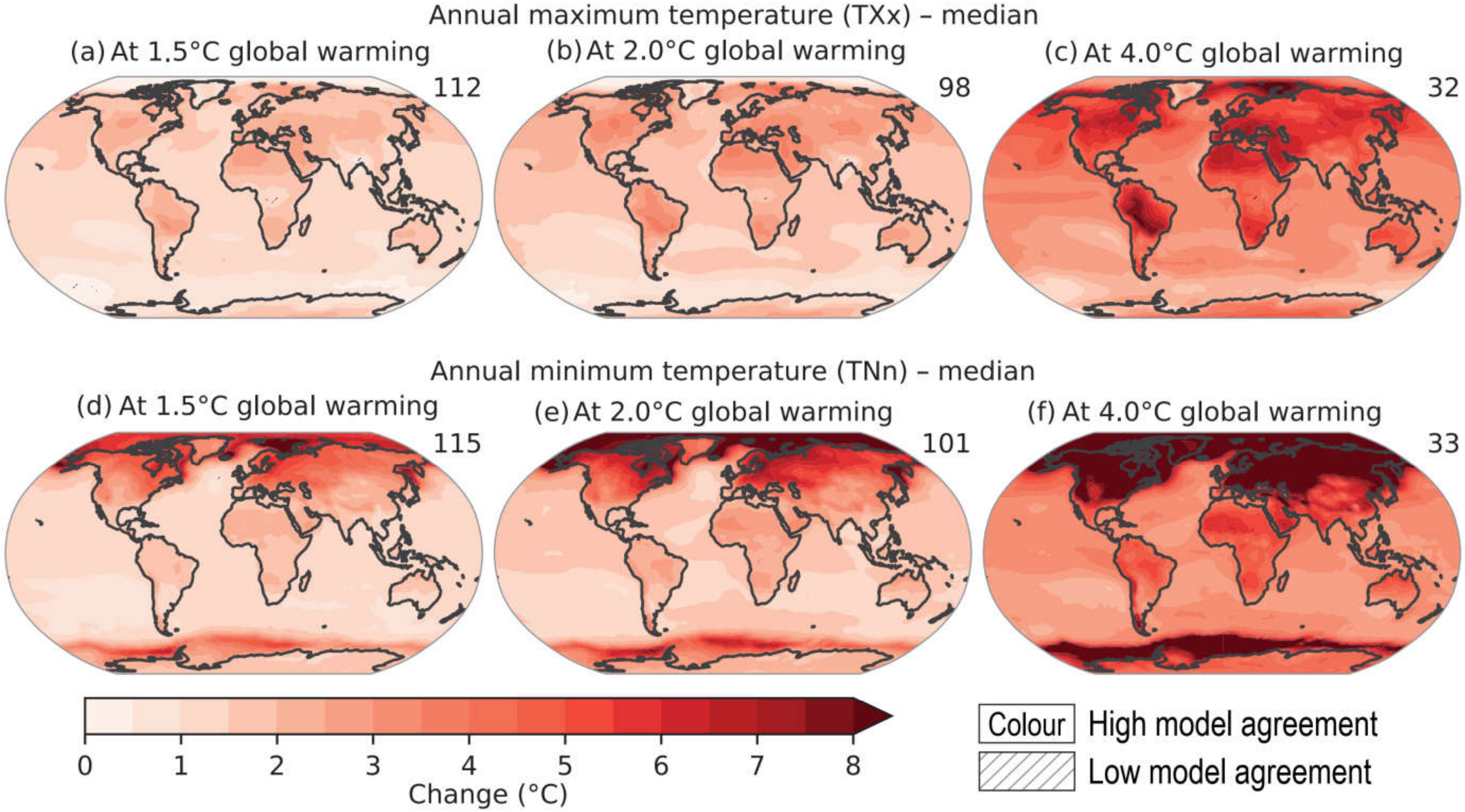

IPCC 2021, Chap. 11

Projected changes in the intensity of extreme temperature events under different global warming levels relative to the 1850–1900 baseline

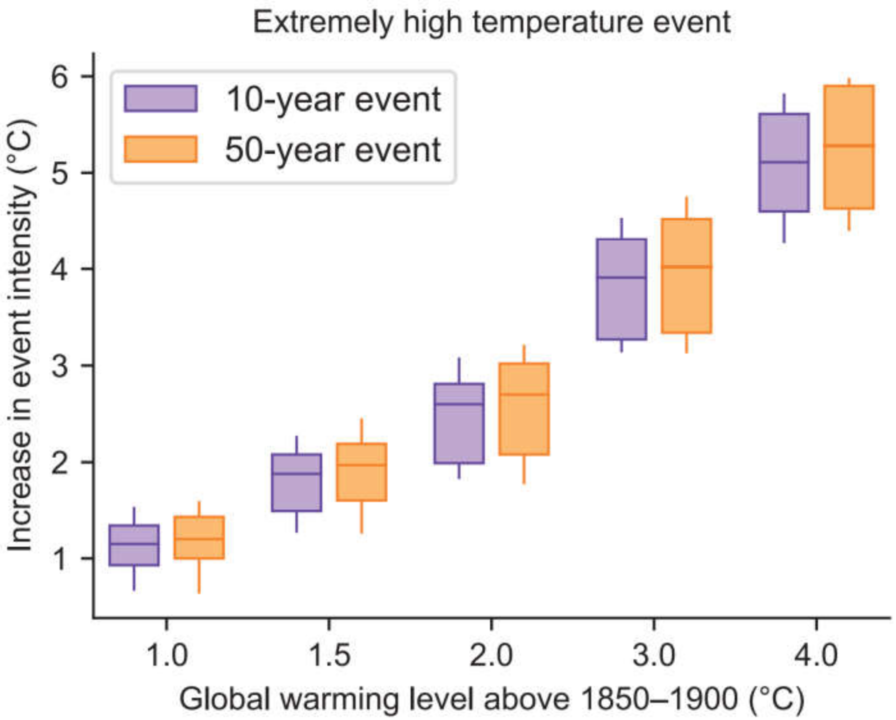

Figure 11.12 | Projected changes in the intensity of extreme temperature events under 1°C, 1.5°C, 2°C, 3°C, and 4°C global warming levels relative to the 1850–1900 baseline. Extreme temperature events are defined as the daily maximum temperatures (TXx) that were exceeded on average once during a 10-year period (10-year event, blue) and once during a 50-year period (50-year event, orange) during the 1850–1900 base period. Results are shown for the global land. For each box plot, the horizontal line and the box represent the median and central 66% uncertainty range, respectively, of the intensity changes across the multi-model ensemble, and the 'whiskers' extend to the 90% uncertainty range. The results are based on the multi-model ensemble from simulations of global climate models contributing to the Coupled Model Intercomparison Project Phase 6 (CMIP6) under different Shared Socio-economic Pathway forcing scenarios. Adapted from Li et al. (2021). Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

IPCC 2021, Chap. 11

Projected changes in the frequency of extreme temperature events under different global warming levels relative to 1850-1900

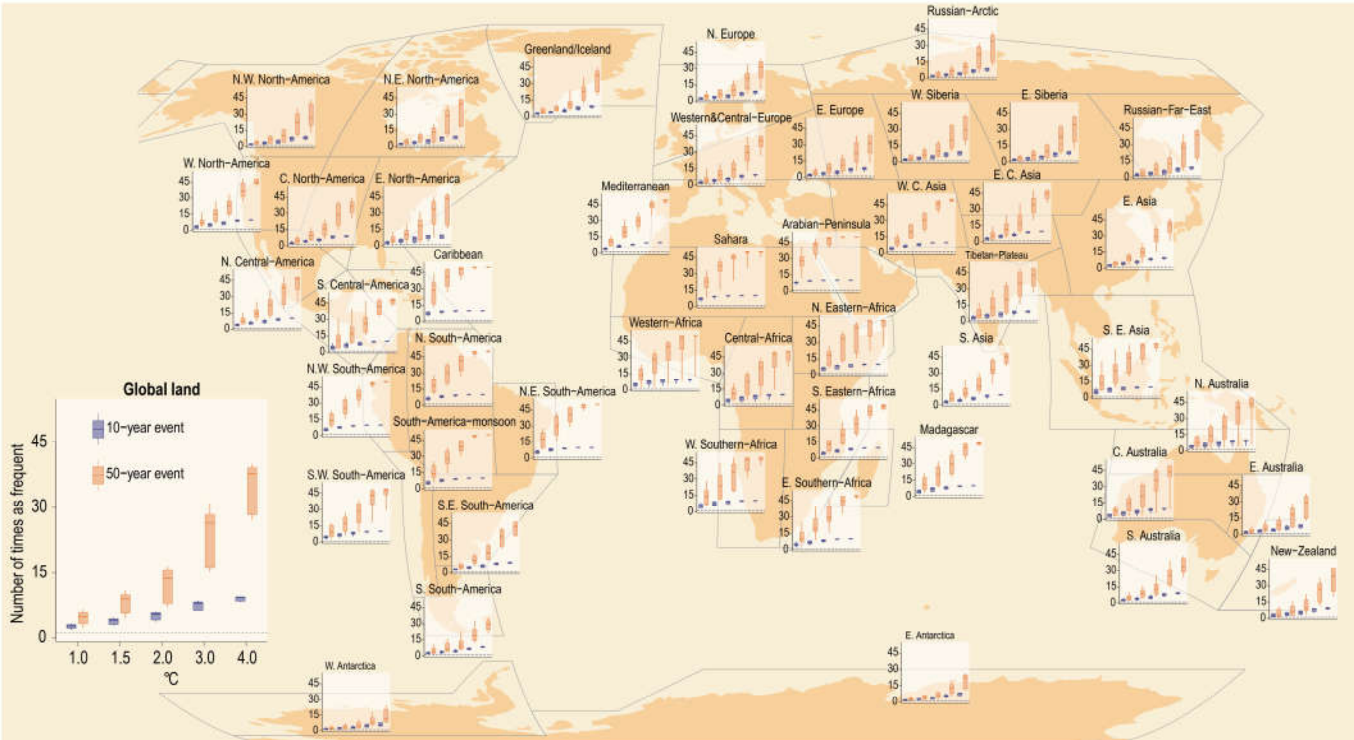

Figure 11.6 | Projected changes in the frequency of extreme temperature events under 1°C, 1.5°C, 2°C, 3°C, and 4°C global warming levels relative to the 1850–1900 baseline. Extreme temperatures are defined as the maximum daily temperatures that were exceeded on average once during a 10-year period (10-year event, blue) and once during a 50-year period (50-year event, orange) during the 1850–1900 base period. Results are shown for the global land area and the AR6 regions. For each box plot, the horizontal line and the box represent the median and central 66% uncertainty range, respectively, of the frequency changes across the multi-model ensemble, and the 'whiskers' extend to the 90% uncertainty range. The dotted line indicates no change in frequency. The results are based on the multi-model ensemble from simulations of global climate models contributing to the Coupled Model Intercomparison Project Phase 6 (CMIP6) under different Shared Socio-economic Pathway forcing scenarios. Adapted from Li et al. (2021). Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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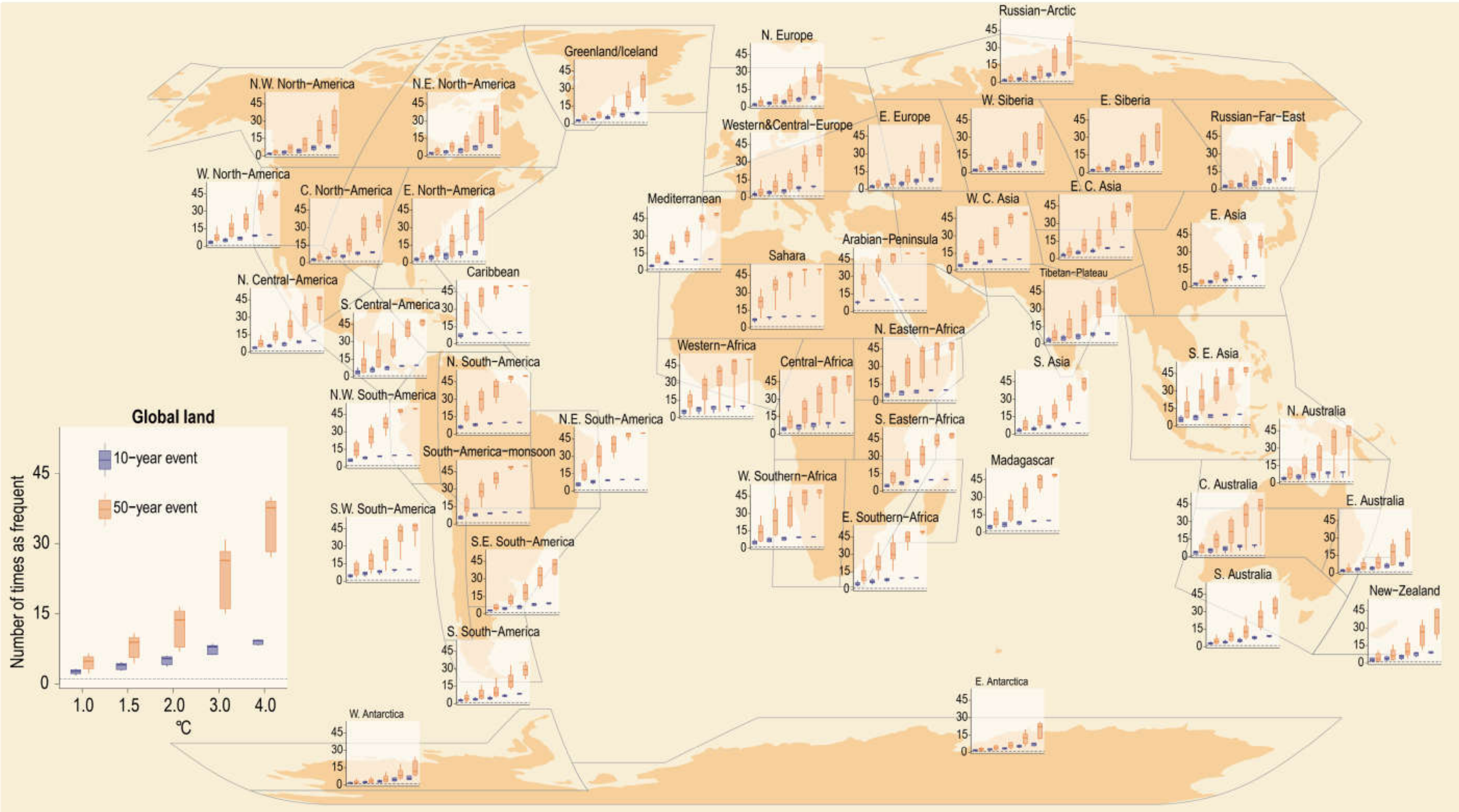

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Statements in the Executive Summary

Heavy Precipitation and Pluvial Floods (1)

The frequency and intensity of heavy precipitation events have *likely* increased at the global scale over a majority of land regions with good observational coverage. Heavy precipitation has *likely* increased on the continental scale over three continents: North America, Europe, and Asia. Regional increases in the frequency and/or intensity of heavy precipitation have been observed with at least medium confidence for nearly half of AR6 regions, including WSAF, ESAF, WSB, SAS, ESB, RFE, WCA, ECA, TIB, EAS, SEA, NAU, NEU, EEU, GIC, WCE, SES, CNA, and ENA. {11.4, 11.9}

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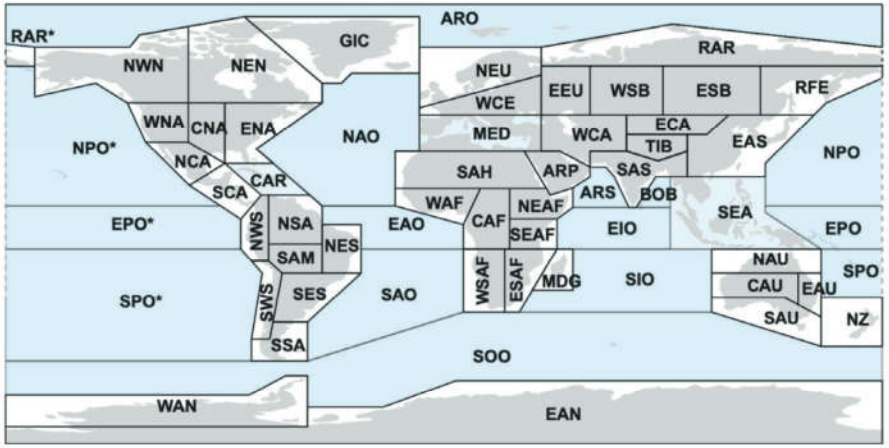
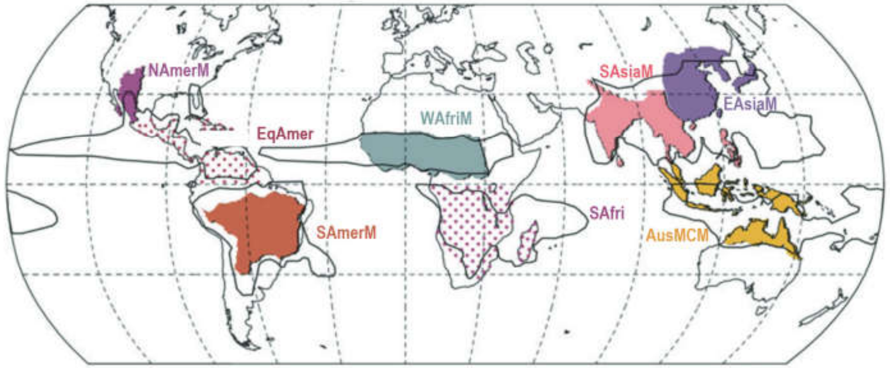
Main region types used in AR6 WGI

(a) AR6 Reference Land and Ocean Regions (entire report)



(b) Typological Regions (example: monsoon domains, Chapter 8)



ARO	Arctic Ocean	NPO	N. Pacific Ocean
ARP	Arabian Peninsula	NSA	N. South America
ARS	Arabian Sea	NWN	N.W. North America
BOB	Bay of Bengal	NWS	N.W. South America
CAF	Central Africa	NZ	New Zealand
CAR	Caribbean	RAR	Russian Arctic
CAU	C. Australia	RFE	Russian Far East
CNA	C. North America	SAH	Sahara
EAN	E. Antarctica	SAM	South American Monsoon
EAO	Equatorial Atlantic Ocean	SAO	S. Atlantic Ocean
EAS	E. Asia	SAS	South Asia
EAU	E. Australia	SAU	S. Australia
ECA	E. Central Asia	SCA	S. Central America
EEU	E. Europe	SEA	S.E. Asia
EIO	Equatorial Indic Ocean	SEAF	S.E. Africa
ENA	E. North America	SES	S.E. South America
EPO	Equatorial Pacific Ocean	SIO	South Indic Ocean
ESAF	E. Southern Africa	SOO	Southern Ocean
ESB	E. Siberia	SPO	S. Pacific Ocean
GIC	Greenland/Iceland	SSA	S. South America
MDG	Madagascar	SWS	S.W. South America
MED	Mediterranean	TIB	Tibetan Plateau
NAO	N. Atlantic Ocean	WAF	W. Africa
NAU	N. Australia	WAN	W. Antarctica
NCA	N. Central America	WCA	W. Central Asia
NEAF	N.E. Africa	WCE	W. & Central Europe
NEN	N.E. North America	WNA	W. North America
NES	N.E. South America	WSAF	W. Southern Africa
NEU	N. Europe	WSB	W. Siberia

AusMCM	Australian-Maritime Continent Monsoon
EAsiaM	E. Asian Monsoon
EqAmer	Equatorial America
NAmerM	N. American Monsoon
SAfri	S. Africa
SAmerM	S. American Monsoon
SAsiaM	S. & S.E. Asian Monsoon
WAfriM	W. African Monsoon

IPCC 2021, Chap. 1

Signs and significance of the observed trends in annual maximum daily precipitation (Rx1day) during 1950–2018

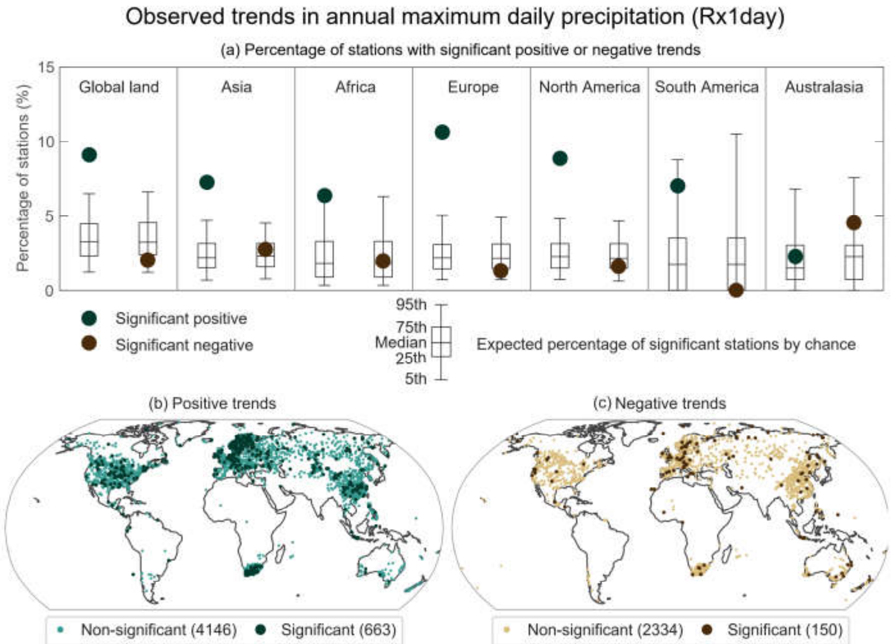


Figure 11.13 | Signs and significance of the observed trends in annual maximum daily precipitation (Rx1day) during 1950–2018 at 8345 stations with sufficient data. (a) Percentage of stations with statistically significant trends in Rx1day; green dots show positive trends and brown dots negative trends. Box and 'whisker' plots indicate the expected percentage of stations with significant trends due to chance estimated from 1000 bootstrap realizations under a no-trend null hypothesis. The boxes mark the median, 25th percentile, and 75th percentile. The upper and lower whiskers show the 97.5th and the 2.5th percentiles, respectively. Maps of stations with positive **(b)** and negative **(c)** trends. The light colour indicates stations with non-significant trends, and the dark colour stations with significant trends. Significance is determined by a two-tailed test conducted at the 5% level. Adapted from Sun et al. (2021). Figure copyright © American Meteorological Society (used with permission). Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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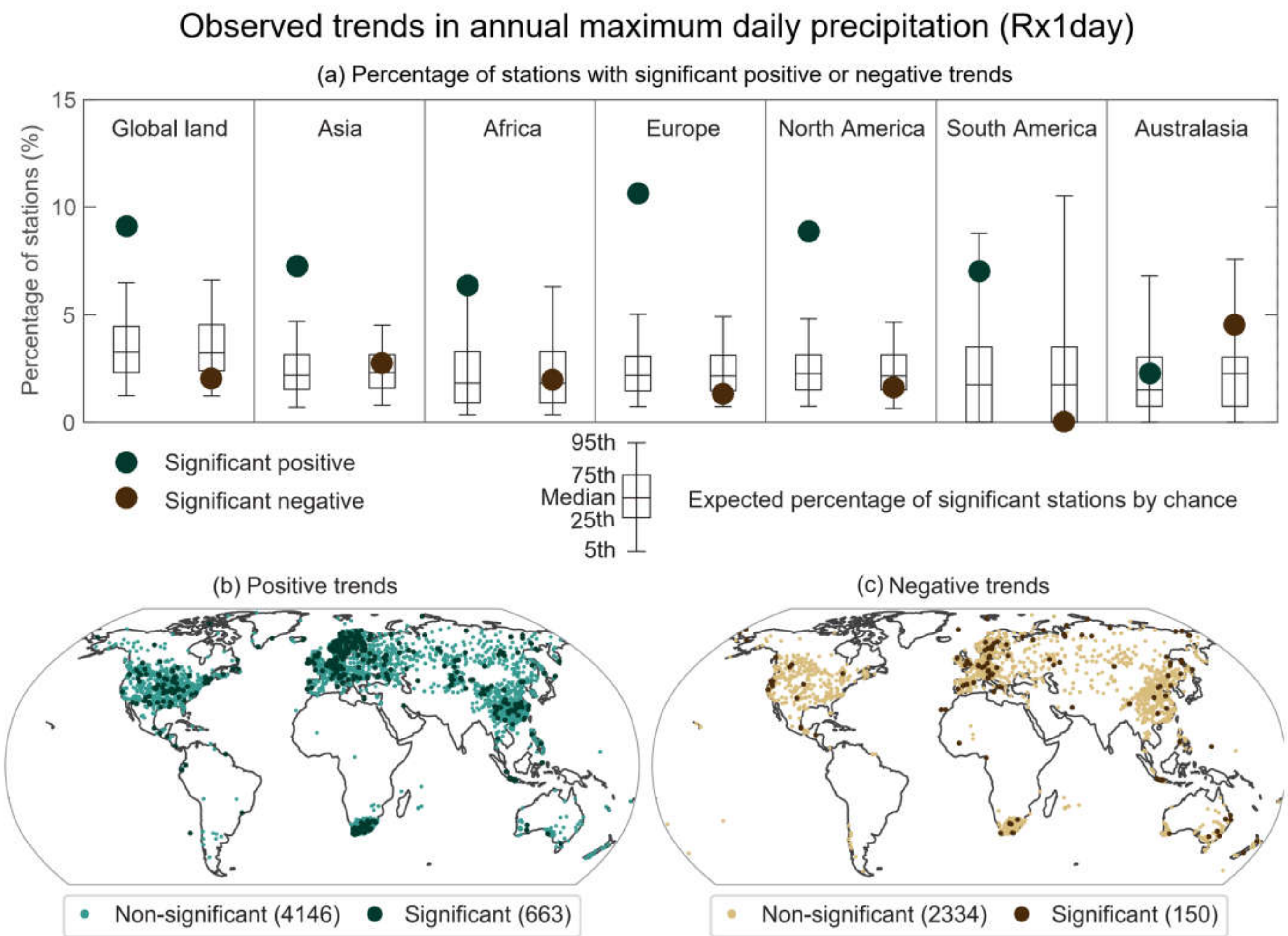

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Statements in the Executive Summary

Heavy Precipitation and Pluvial Floods (2)

Human influence, in particular greenhouse gas emissions, is *likely* the main driver of the observed global-scale intensification of heavy precipitation over land regions. It is *likely* that human-induced climate change has contributed to the observed intensification of heavy precipitation at the continental scale in North America, Europe and Asia. Evidence of a human influence on heavy precipitation has emerged in some regions (*high confidence*). {11.4, 11.9, Table 11.1}

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Statements in the Executive Summary

Heavy Precipitation and Pluvial Floods (3)

Heavy precipitation will generally become more frequent and more intense with additional global warming. At a global warming level of 4°C relative to the pre-industrial level, very rare (e.g., one in 10 or more years) heavy precipitation events would become more frequent and more intense than in the recent past, on the global scale (*virtually certain*) and in all continents and AR6 regions. The increase in frequency and intensity is *extremely likely* for most continents and *very likely* for most AR6 regions.

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Statements in the Executive Summary

Heavy Precipitation and Pluvial Floods (3)

Heavy precipitation will generally become more frequent and more intense with additional global warming. At a global warming level of 4°C relative to the pre-industrial level, very rare (e.g., one in 10 or more years) heavy precipitation events would become more frequent and more intense than in the recent past, on the global scale (*virtually certain*) and in all continents and AR6 regions. The increase in frequency and intensity is *extremely likely* for most continents and *very likely* for most AR6 regions. At the global scale, the intensification of heavy precipitation will follow the rate of increase in the maximum amount of moisture that the atmosphere can hold as it warms (*high confidence*), of about 7% per 1°C of global warming. The increase in the frequency of heavy precipitation events will be non-linear with more warming and will be higher for rarer events (*high confidence*), with a *likely* doubling and tripling in the frequency of 10-year and 50-year events, respectively, compared to the recent past at 4°C of global warming. Increases in the intensity of extreme precipitation at regional scales will vary, depending on the amount of regional warming, changes in atmospheric circulation and storm dynamics (*high confidence*). {11.4, Box 11.1}

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Projected changes in annual maximum daily precipitation

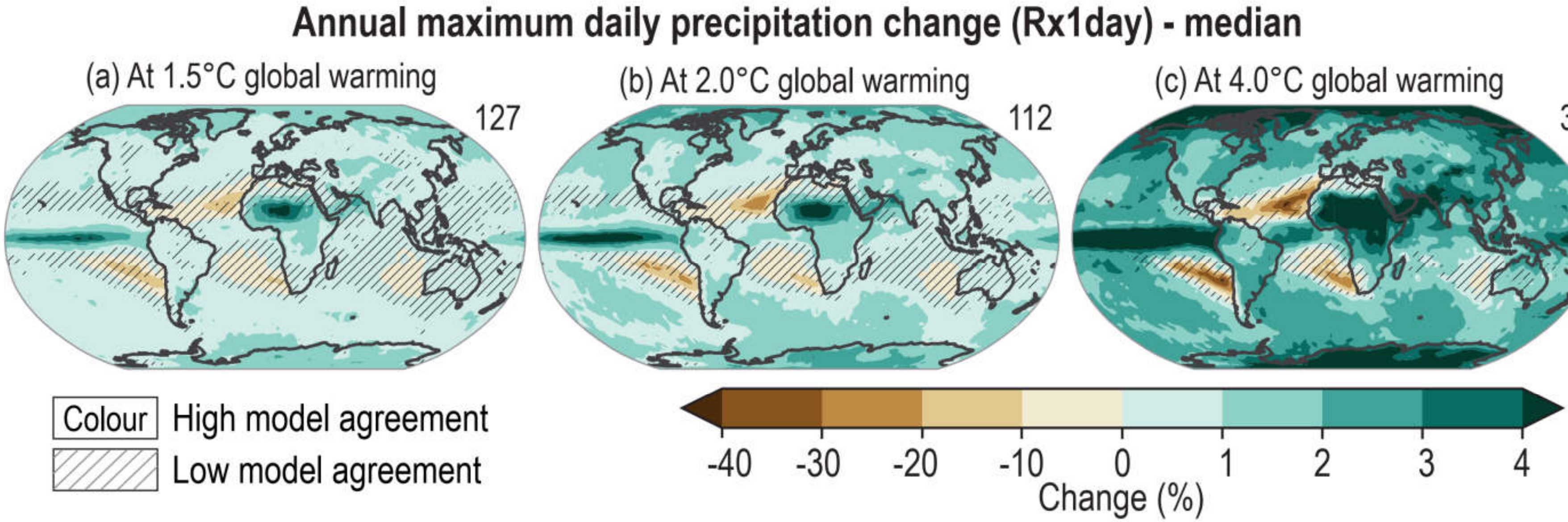

Figure 11.16 | Projected changes in annual maximum daily precipitation at (a) 1.5°C, (b) 2°C, and (c) 4°C of global warming compared to the 1850–1900 baseline. Results are based on simulations from the Coupled Model Intercomparison Project Phase 6 (CMIP6) multi-model ensemble under the Shared Socio-economic Pathway (SSP), SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios. The numbers on the top right indicate the number of simulations included. Uncertainty is represented using the simple approach: no overlay indicates regions with high model agreement, where ≥80% of models agree on the sign of change; diagonal lines indicate regions with low model agreement, where <80% of models agree on the sign of change. For more information on the simple approach, please refer to the Cross-Chapter Box Atlas 1. For details on the methods see Supplementary Material 11.SM.2. Changes in Rx1day are also displayed in the Interactive Atlas. Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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Projected changes in the intensity of extreme precipitation events under different global warming levels relative to the 1850–1900 baseline

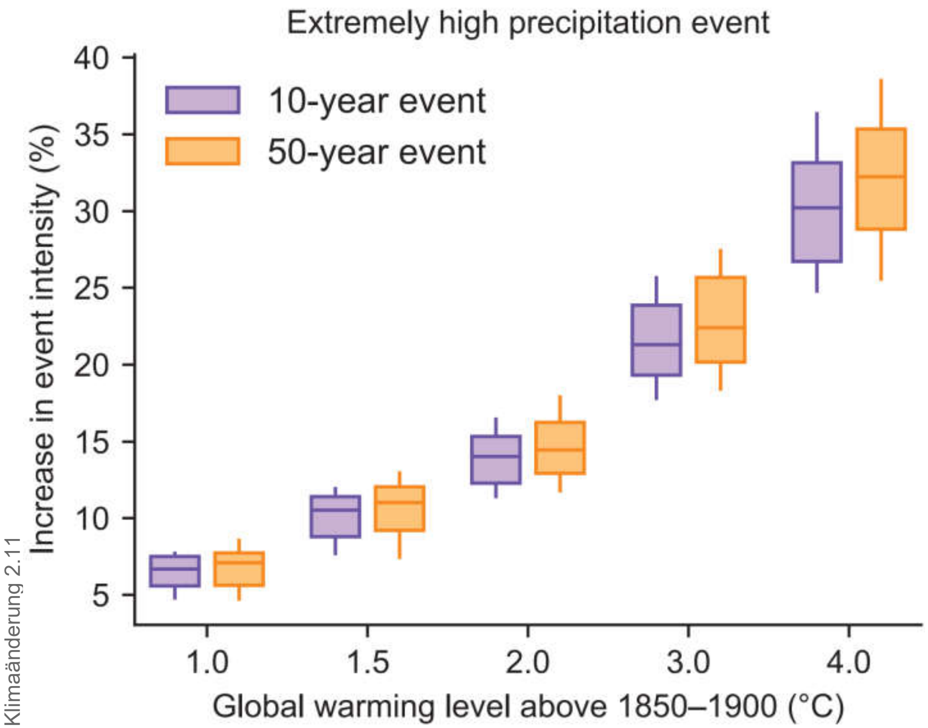

Figure 11.15 | Projected changes in the intensity of extreme precipitation events under 1°C, 1.5°C, 2°C, 3°C, and 4°C global warming levels relative to the 1850–1900 baseline. Extreme precipitation events are defined as the annual maximum daily maximum precipitation (Rx1day) that was exceeded on average once during a 10-year period (10-year event, blue) and once during a 50-year period (50-year event, orange) during the 1850–1900 base period. Results are shown for the global land. For each box plot, the horizontal line and the box represent the median and central 66% uncertainty range, respectively, of the intensity changes across the multi-model median, and the 'whiskers' extend to the 90% uncertainty range. The results are based on the multi-model ensemble estimated from simulations of global climate models contributing to the Coupled Model Intercomparison Project Phase 6 (CMIP6) under different Shared Socio-economic Pathway forcing scenarios. Based on Li et al. (2021). Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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Heavy Precipitation and Pluvial Floods (4)

The projected increase in the intensity of extreme precipitation translates to an increase in the frequency and magnitude of pluvial floods – surface water and flash floods – (high confidence), as pluvial flooding results from precipitation intensity exceeding the capacity of natural and artificial drainage systems. {11.4}

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Statements in the Executive Summary

River Floods

Significant trends in peak streamflow have been observed in some regions over the past decades (*high confidence*). The seasonality of river floods has changed in cold regions where snow-melt is involved, with an earlier occurrence of peak streamflow (*high confidence*). {11.5}

Global hydrological models project a larger fraction of land areas to be affected by an increase in river floods than by a decrease in river floods (*medium confidence*). Regional changes in river floods are more uncertain than changes in pluvial floods because complex hydrological processes and forcings, including land cover change and human water management, are involved. {11.5}

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Statements in the Executive Summary

Droughts (1)

Different drought types exist, and they are associated with different impacts and respond differently to increasing greenhouse gas concentrations. Precipitation deficits and changes in evapotranspiration govern net water availability. A lack of sufficient soil moisture, sometimes amplified by increased atmospheric evaporative demand, results in agricultural and ecological drought. Lack of runoff and surface water result in hydrological drought. {11.6}

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Droughts (2)

Human-induced climate change has contributed to increases in agricultural and ecological droughts in some regions due to evapotranspiration increases (*medium confidence*). Increases in evapotranspiration have been driven by increases in atmospheric evaporative demand induced by increased temperature, decreased relative humidity and increased net radiation (*high confidence*). Trends in precipitation are not a main driver in affecting global-scale trends in drought (*medium confidence*), but have induced increases in meteorological droughts in a few AR6 regions (NES: *high confidence*; WAF, CAF, ESAF, SAM, SWS, SSA, SAS: *medium confidence*).

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Droughts (2)

Human-induced climate change has contributed to increases in agricultural and ecological droughts in some regions due to evapotranspiration increases (*medium confidence*). Increases in evapotranspiration have been driven by increases in atmospheric evaporative demand induced by increased temperature, decreased relative humidity and increased net radiation (*high confidence*). Trends in precipitation are not a main driver in affecting global-scale trends in drought (*medium confidence*), but have induced increases in meteorological droughts in a few AR6 regions (NES: *high confidence*; WAF, CAF, ESAF, SAM, SWS, SSA, SAS: *medium confidence*). Increasing trends in agricultural and ecological droughts have been observed on all continents (WAF, CAF, WSAF, ESAF, WCA, ECA, EAS, SAU, MED, WCE, WNA, NES: *medium confidence*), but decreases only in one AR6 region (NAU: *medium confidence*). Increasing trends in hydrological droughts have been observed in a few AR6 regions (MED: *high confidence*; WAF, EAS, SAU: *medium confidence*). Regional-scale attribution shows that human-induced climate change has contributed to increased agricultural and ecological droughts (MED, WNA), and increased hydrological drought (MED) in some regions (*medium confidence*). {11.6, 11.9}

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Observed lin. trend for (a) consecutive dry days (CDD) during 1960–2018, (b) standard. precipitation index (SPI) and (c) standard. precip.-evap. index (SPEI) during 1951–2016

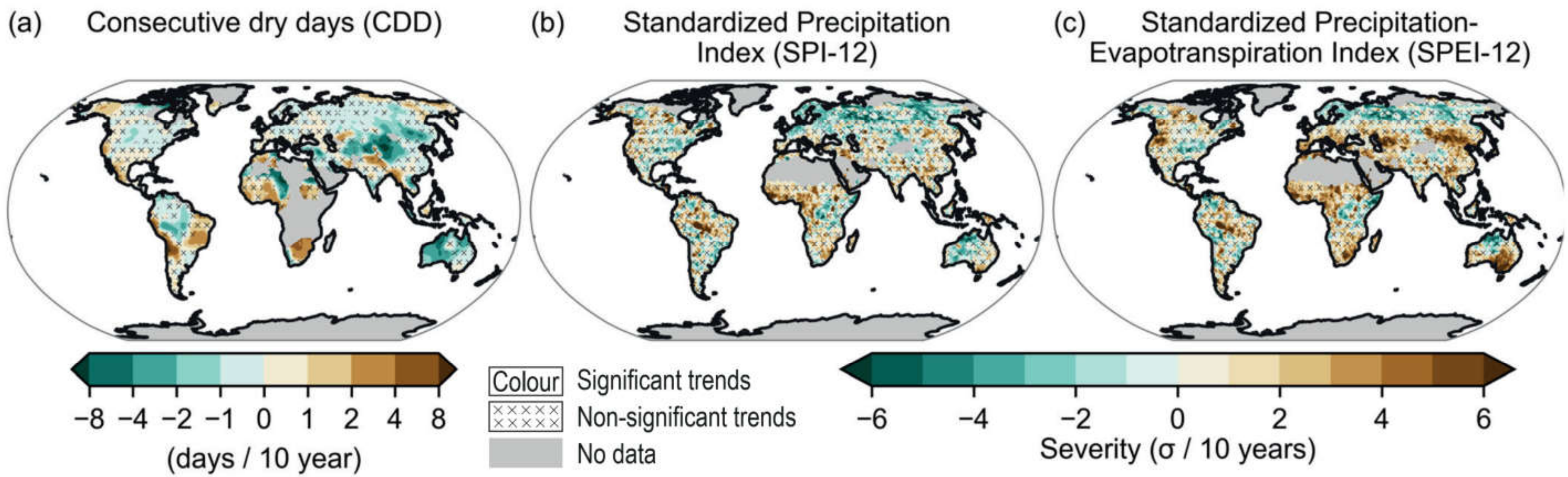

Figure 11.17 | Observed linear trend for (a) consecutive dry days (CDD) during 1960–2018, (b) standardized precipitation index (SPI) and (c) standardized precipitation-evapotranspiration index (SPEI) during 1951–2016. CDD data are from the HadEx3 dataset (Dunn et al., 2020), trend calculation of CDD as in Figure 11.9. Drought severity is estimated using 12-month SPI (SPI-12) and 12-month SPEI (SPEI-12). SPI and SPEI datasets are from Spinoni et al. (2019). The threshold to identify drought episodes was set at -1 SPI/SPEI units. Areas without sufficient data are shown in grey. No overlay indicates regions where the trends are significant at the p = 0.1 level. Crosses indicate regions where trends are not significant. For details on the methods see Supplementary Material 11.SM.2. Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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Droughts (3a)

More regions are affected by increases in agricultural and ecological droughts with increasing global warming (*high confidence*). Several regions will be affected by more severe agricultural and ecological droughts even if global warming is stabilised at 2°C, including MED, WSAF, SAM and SSA (*high confidence*), and ESAF, MDG, EAU, SAU, SCA, CAR, NSA, NES, SWS, WCE, NCA, WNA and CNA (*medium confidence*). Some regions are also projected to be affected by more severe agricultural and ecological droughts at 1.5°C (MED, WSAF, ESAF, SAU, NSA, SAM, SSA, CNA, *medium confidence*). At 4°C of global warming, about 50% of all inhabited AR6 regions would be affected by increases in agricultural and ecological droughts (WCE, MED, CAU, EAU, SAU, WCA, EAS, SCA, CAR, NSA, NES, SAM, SWS, SSA, NCA, CNA, ENA, WNA, WSAF, ESAF, MDG: *medium confidence* or *higher*), and only two regions (NEAF, SAS) would experience decreases in agricultural and ecological drought (*medium confidence*). There is high confidence that the projected increases in agricultural and ecological droughts are strongly affected by evapotranspiration increases associated with enhanced atmospheric evaporative demand. ...

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Droughts (3b)

... Several regions are projected to be more strongly affected by hydrological droughts with increasing global warming (at 4°C of global warming: NEU, WCE, EEU, MED, SAU, WCA, SCA, NSA, SAM, SWS, SSA, WNA, WSAF, ESAF, MDG: *medium confidence* or *higher*). There is *low confidence* that effects of enhanced atmospheric carbon dioxide (CO_2) concentrations on plant water-use efficiency alleviate extreme agricultural and ecological droughts in conditions characterized by limited soil moisture and enhanced atmospheric evaporative demand. There is also *low confidence* that these effects will substantially reduce global plant transpiration and the severity of hydrological droughts. There is *high confidence* that the land carbon sink will become less efficient due to soil moisture limitations and associated drought conditions in some regions in higher-emissions scenarios, in particular under global warming levels above 4°C. {11.6, 11.9, Cross-Chapter Box 5.1}

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Projected changes in the intensity and frequency drought under different global warming levels relative to the 1850–1900 baseline

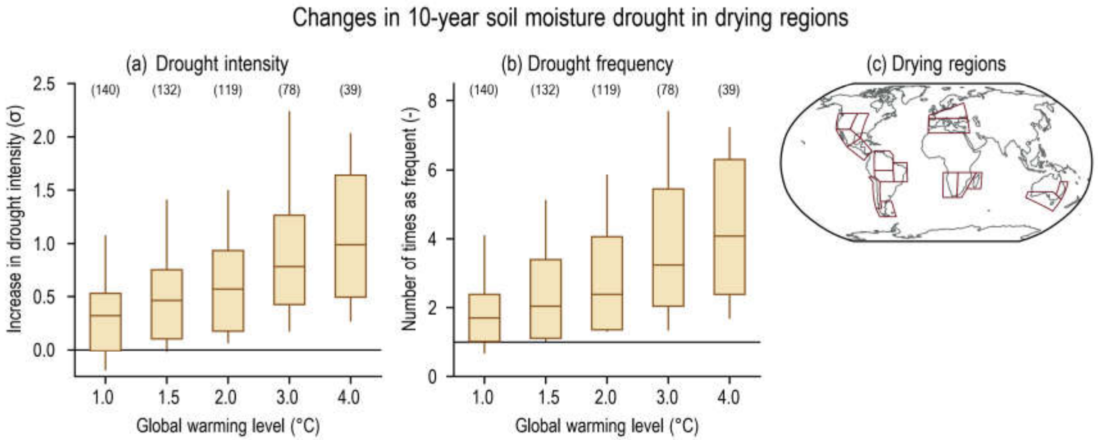

Figure 11.18 | Projected changes in (a) the intensity and (b) the frequency of drought under 1°C, 1.5°C, 2°C, 3°C, and 4°C global warming levels relative to the 1850–1900 baseline. (c) Summaries are computed for the AR6 regions in which there is at least medium confidence in an increase in agriculture/ecological drought at the 2°C global warming level ('drying regions'), including Western North America, Central North America, North Central America, Southern Central America, Northern South America, North-Eastern South America, South American Monsoon, South-Western South America, Southern South America, West and Central Europe, Mediterranean, West Southern Africa, East Southern Africa, Madagascar, Eastern Australia, Southern Australia. Caribbean is not included in the calculation because the number of land grid points was too small. A drought event is defined as a 10-year drought event whose annual mean soil moisture was below its 10th percentile from the 1850–1900 base period. For each box plot, the horizontal line and the box represent the median and central 66% uncertainty range, respectively, of the frequency or the intensity changes across the multi-model ensemble, and the 'whiskers' extend to the 90% uncertainty range. The line of zero in (a) indicates no change in intensity, while the line of one in (b) indicates no change in frequency. The results are based on the multi-model ensemble estimated from simulations of global climate models contributing to the Coupled Model Intercomparison Project Phase 6 (CMIP6) under different Shared Socio-economic Pathway (SSP) forcing scenarios. Intensity changes in (a) are expressed as standard deviations of the interannual variability in the period 1850–1900 of the corresponding model. For details on the methods see Supplementary Material 11.SM.2. Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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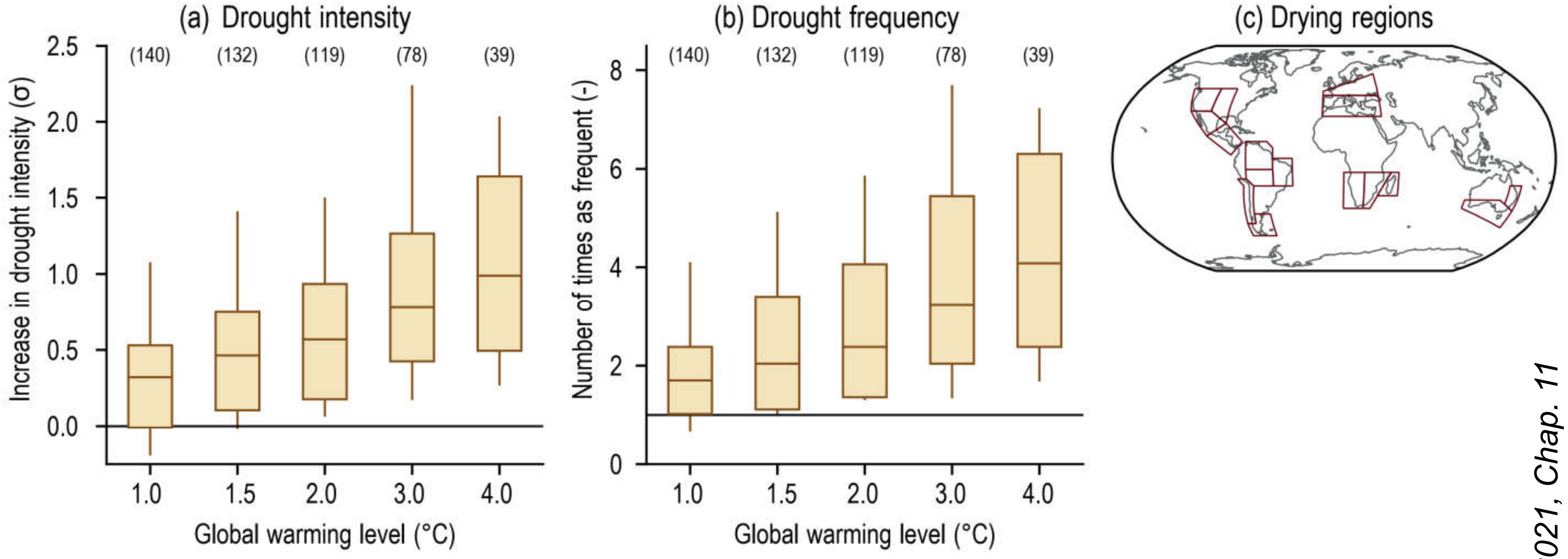
Changes in 10-year soil moisture drought in drying regions



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Projected changes in the number of consecutive dry days (CDD), annual mean soil moisture over the total column, and the frequency and intensity of 1-in-10-year soil moisture drought for JJA and DJF the intensity and frequency drought under different global warming levels relative to the 1850–1900 baseline

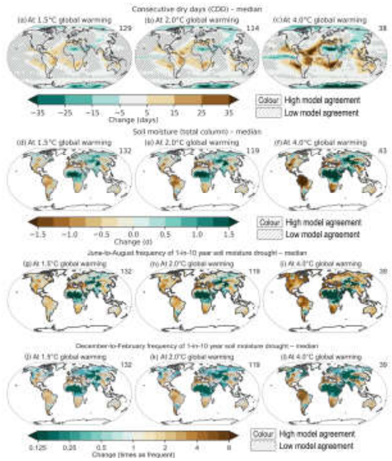

Figure 11.19 | Projected changes in (a–c) the number of consecutive dry days (CDD), (d–f) annual mean soil moisture over the total column, and (g–l) the frequency and intensity of 1-in-10-year soil moisture drought for the June-to-August and December-to-February seasons at 1.5°C, 2°C, and 4°C of global warming compared to the 1850–1900 baseline. The unit for soil moisture change is the standard deviation of interannual variability in soil moisture during 1850–1900. Standard deviation is a widely used metric in characterizing drought severity. A projected reduction in mean soil moisture by one standard deviation corresponds to soil moisture conditions typical of about 1-in-6-year droughts during 1850–1900 becoming the norm in the future. Results are based on simulations from the Coupled Model Intercomparison Project Phase 6 (CMIP6) multi-model ensemble under the Shared Socio-economic Pathway (SSP), SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios. The numbers in the top right indicate the number of simulations included. Uncertainty is represented using the simple approach: no overlay indicates regions with high model agreement, where ≥80% of models agree on the sign of change; diagonal lines indicate regions with low model agreement, where <80% of models agree on the sign of change. For more information on the simple approach, please refer to the Cross-Chapter Box Atlas 1. For details on the methods see Supplementary Material 11.SM.2. Changes in CDDs are also displayed in the Interactive Atlas. Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

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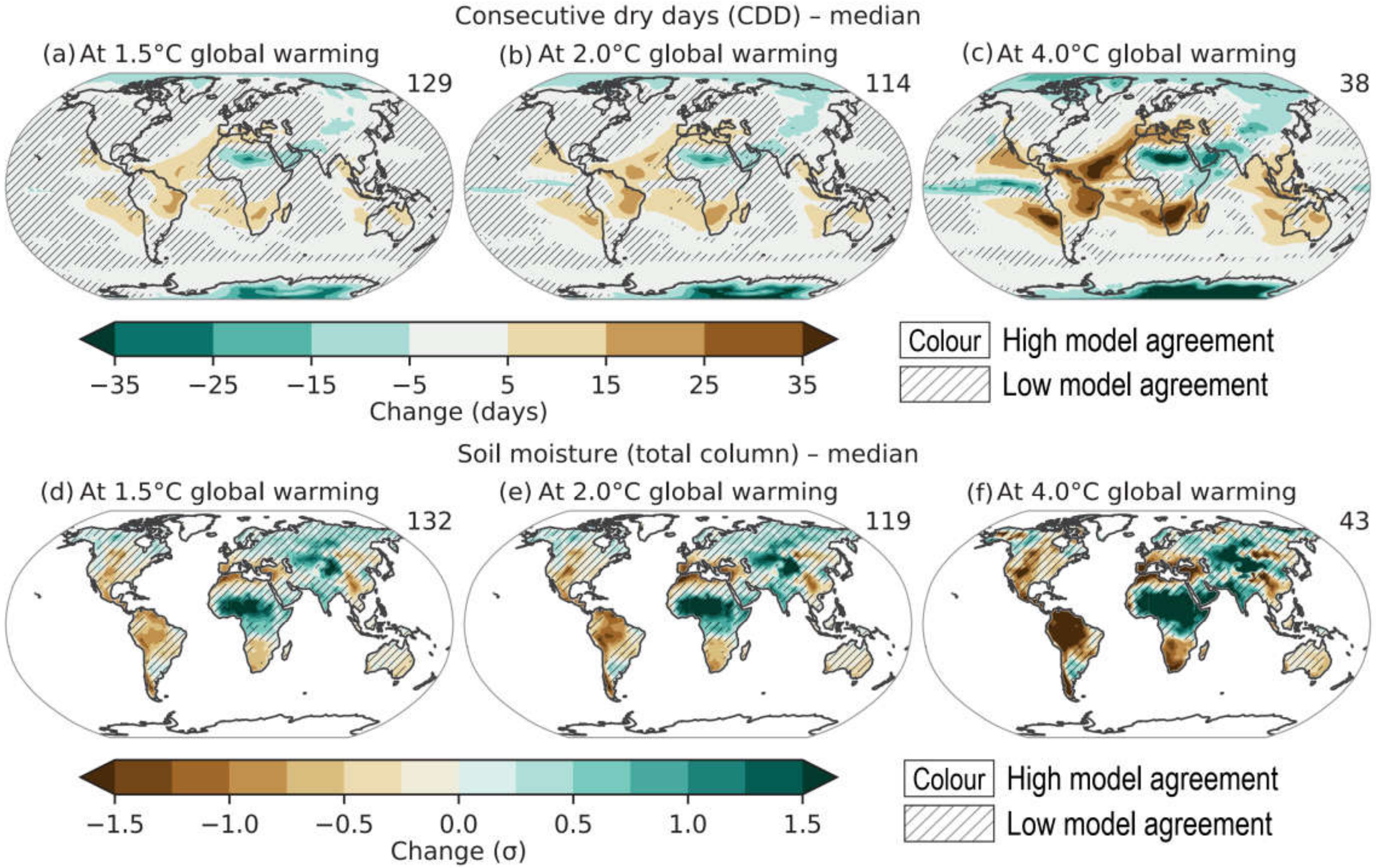

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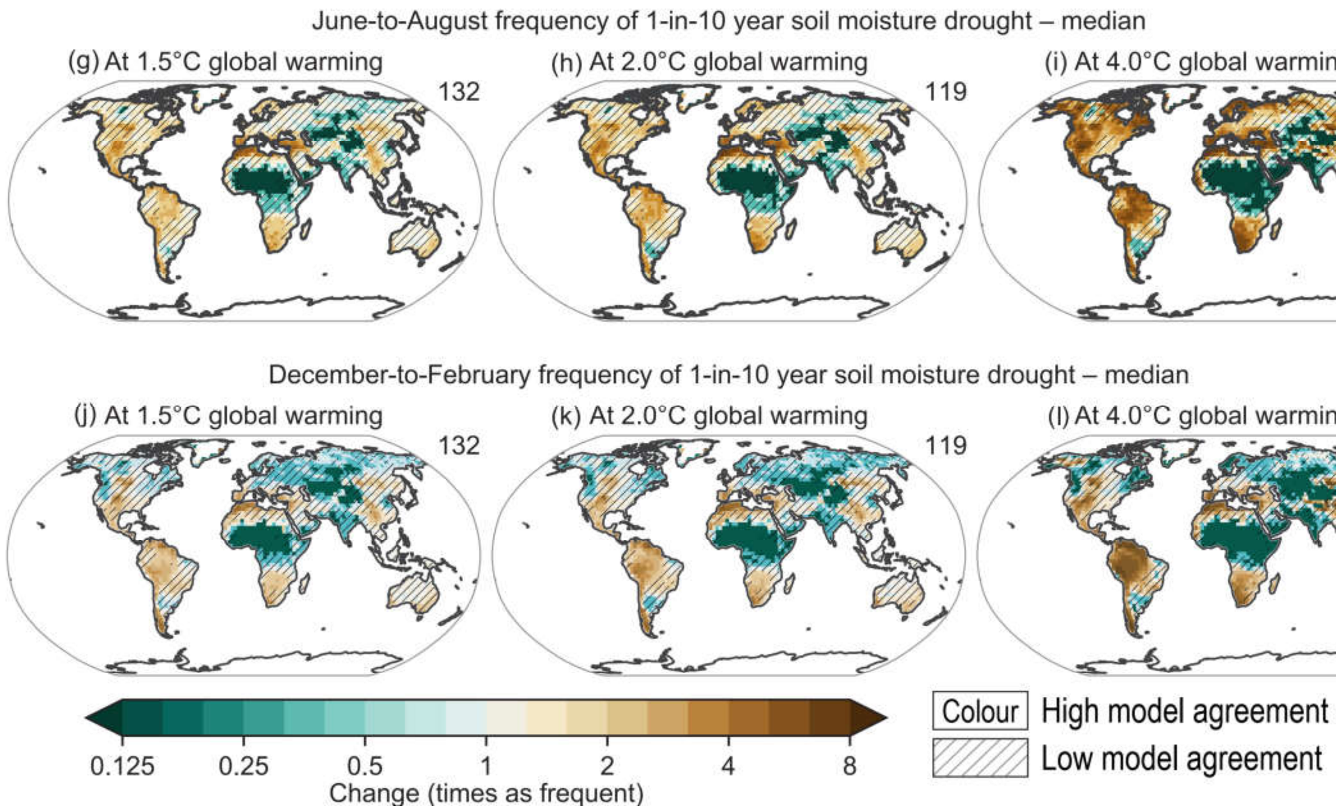

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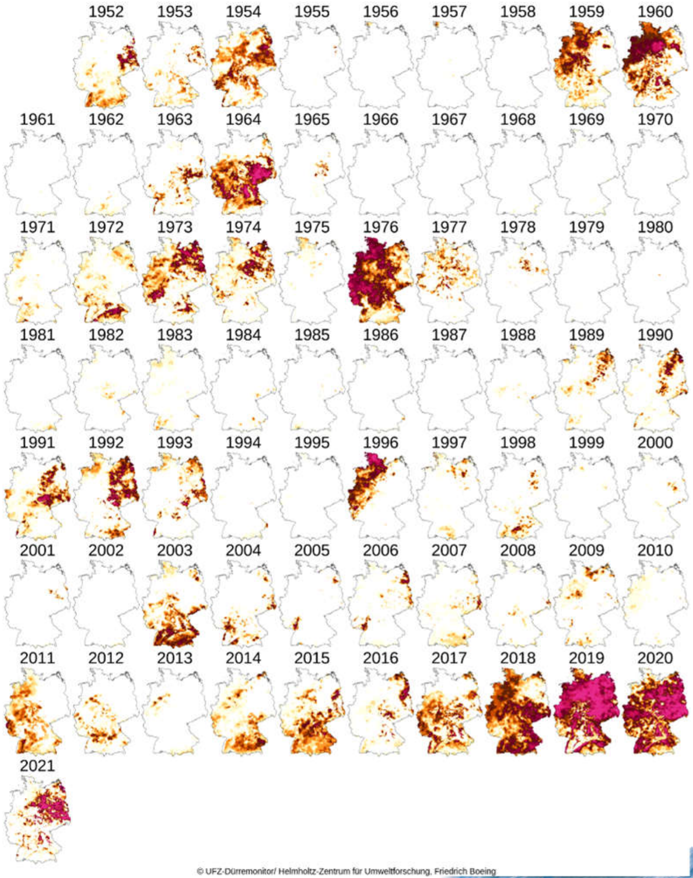
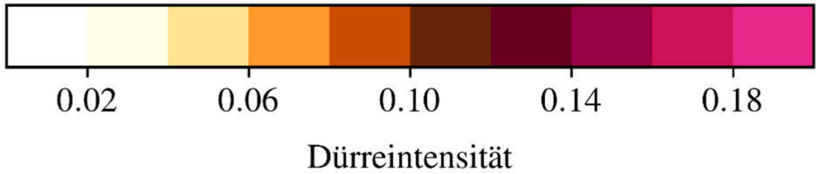
Dürreintensitäten im Gesamtboden
in der Vegetationsperiode April bis Oktober

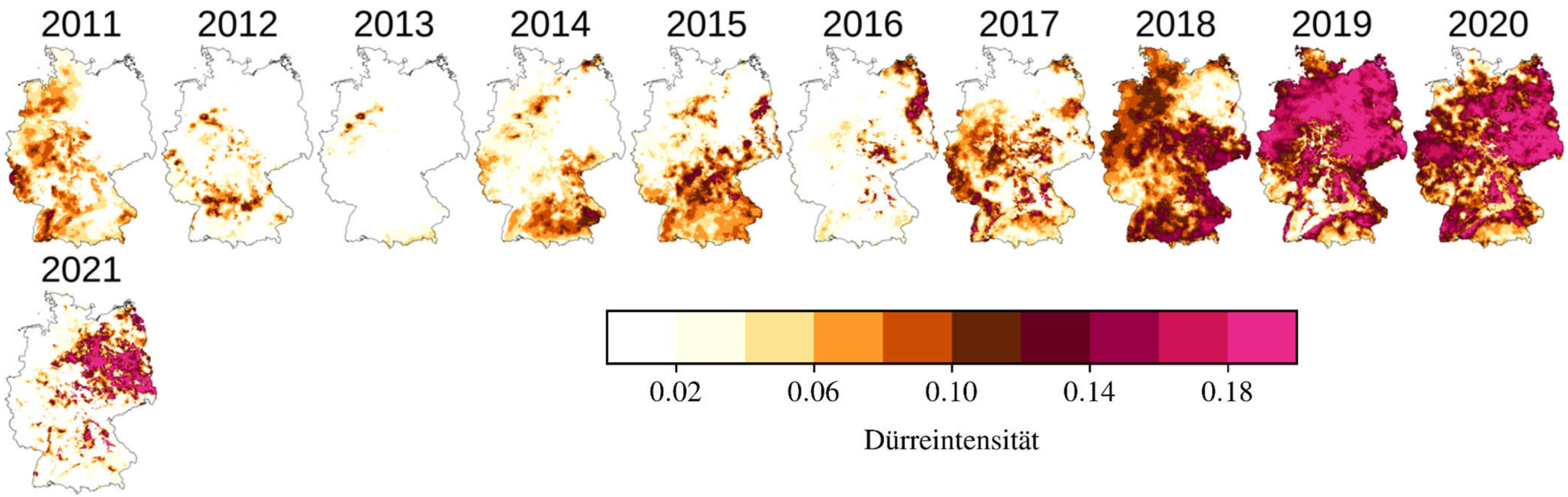




[Dürren 1952 - 2021 (jährlich) - Helmholtz-Zentrum für Umweltforschung UFZ](https://www.ufz.de/index.php?de=47252)

https://www.ufz.de/index.php?de=47252

Dürreintensitäten im Gesamtboden in der Vegetationsperiode April bis Oktober



[Dürren 1952 - 2021 (jährlich) - Helmholtz-Zentrum für Umweltforschung UFZ](https://www.ufz.de/index.php?de=47252)
https://www.ufz.de/index.php?de=47252

Statements in the Executive Summary

Extreme Storms, Including Tropical Cyclones (1)

The average and maximum rain rates associated with tropical cyclones (TCs), extratropical cyclones and atmospheric rivers across the globe, and severe convective storms in some regions, increase in a warming world (high confidence). Available event attribution studies of observed strong TCs provide medium confidence for a human contribution to extreme TC rainfall. Peak TC rain rates increase with local warming at least at the rate of mean water vapour increase over oceans (about 7% per 1^{o}C of warming) and in some cases exceeding this rate due to increased low-level moisture convergence caused by increases in TC wind intensity (medium confidence). {11.7, 11.4, Box 11.1}

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Statements in the Executive Summary

Extreme Storms, Including Tropical Cyclones (2)

It is *likely* that the global proportion of Category 3–5 tropical cyclone instances has increased over the past four decades. The average location where TCs reach their peak wind intensity has *very likely* migrated poleward in the western North Pacific Ocean since the 1940s, and TC translation speed has *likely* slowed over the conterminous USA since 1900. Evidence of similar trends in other regions is not robust. The global frequency of TC rapid intensification events has *likely* increased over the past four decades. None of these changes can be explained by natural variability alone (*medium confidence*).

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Statements in the Executive Summary

Extreme Storms, Including Tropical Cyclones (2)

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The proportion of intense TCs, average peak TC wind speeds, and peak wind speeds of the most intense TCs will increase on the global scale with increasing global warming (*high confidence*). The total global frequency of TC formation will decrease or remain unchanged with increasing global warming (*medium confidence*). {11.7.1}

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Summary schematic of past and projected changes in tropical cyclone (TC), extratropical cyclone (ETC), atmospheric river (AR), and severe convective storm (SCS) behaviour

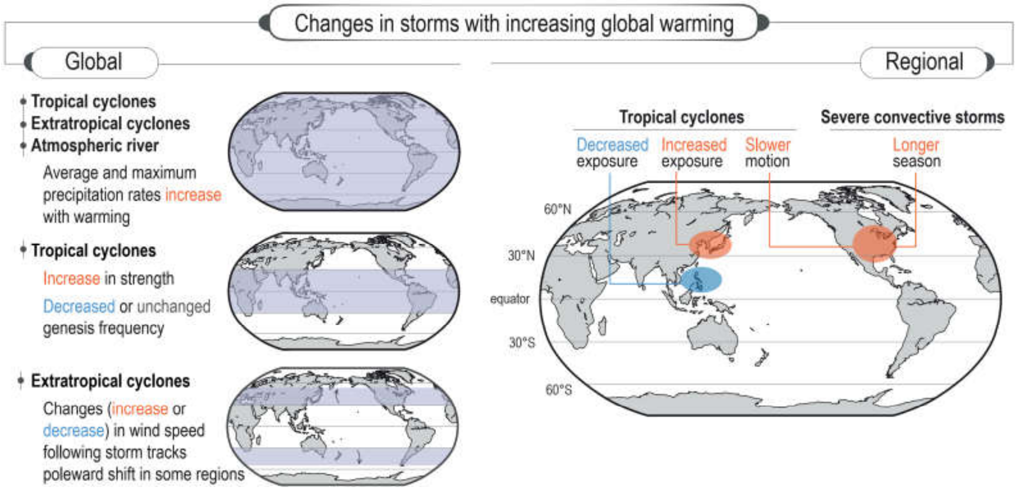

Figure 11.20 | Summary schematic of past and projected changes in tropical cyclone (TC), extratropical cyclone (ETC), atmospheric river (AR), and severe convective storm (SCS) behaviour. Global changes (blue shading) from top to bottom: **(i)** Increased mean and maximum rain rates in TCs, ETCs, and ARs [past (*low confidence* due to lack of reliable data) and projected (*high confidence*)]; **(ii)** Increased proportion of stronger TCs [past (*medium confidence*) and projected (*high confidence*)]; **(iii)** Decrease or no change in global frequency of TC genesis [past (*low confidence* due to lack of reliable data) and projected (*medium confidence*)]; and **(iv)** 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, from left to right: **(i)** Poleward TC migration in the western North Pacific and subsequent changes in TC exposure [past (*medium confidence*) and projected (*medium confidence*)]; **(ii)** 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 directed studies)]; and **(iii)** Increase in mean and maximum SCS rain rate and increase in spring SCS frequency and season length over the contiguous USA [past (*low confidence* due to lack of reliable data) and projected (*medium confidence*)].

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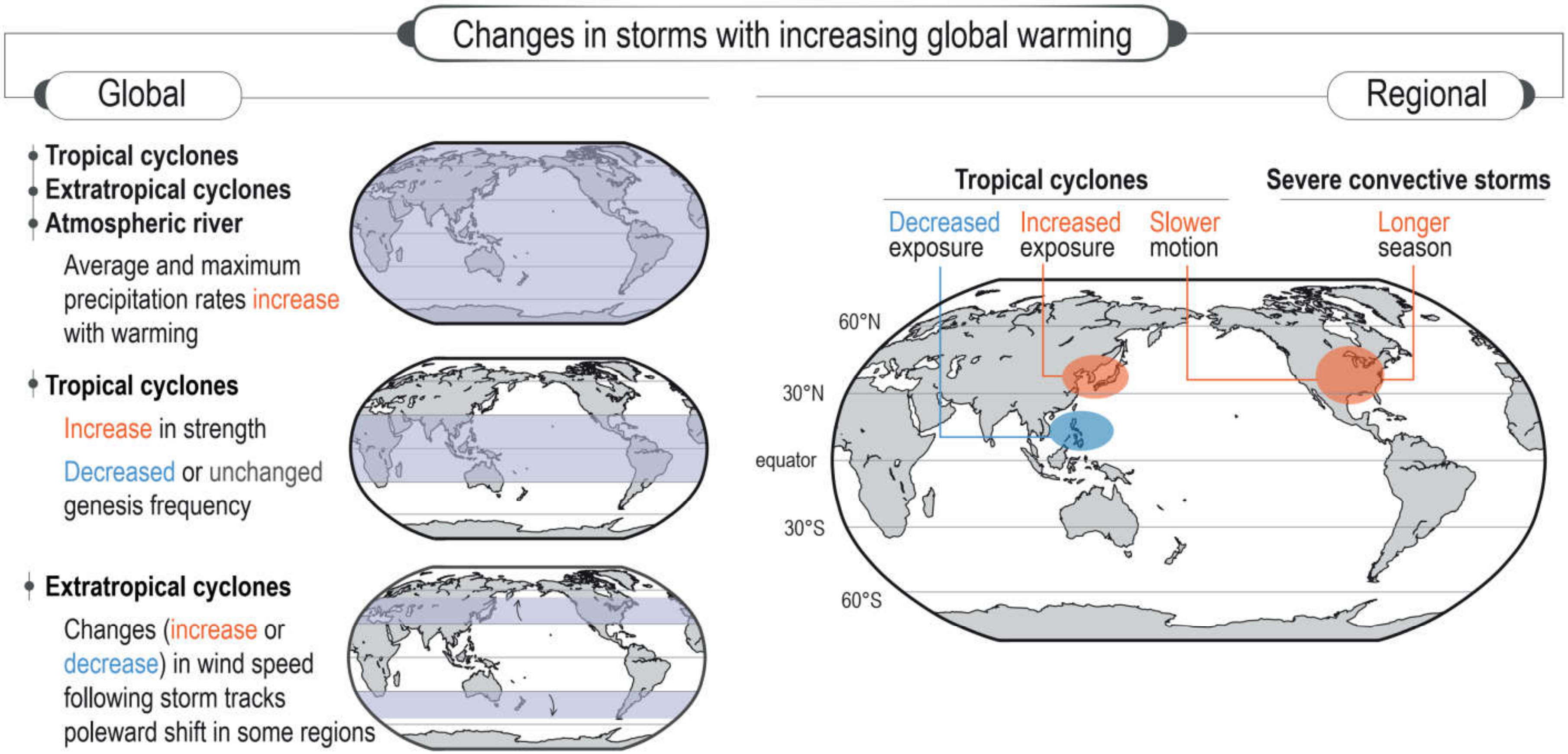

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Extreme Storms, Including Tropical Cyclones (3)

There is *low confidence* in past changes of maximum wind speeds and other measures of dynamical intensity of extratropical cyclones. Future wind speed changes are expected to be small, although poleward shifts in the storm tracks could lead to substantial changes in extreme wind speeds in some regions (*medium confidence*). There is *low confidence* in past trends in characteristics of severe convective storms, such as hail and severe winds, beyond an increase in precipitation rates. The frequency of spring severe convective storms is projected to increase in the USA, leading to a lengthening of the severe convective storm season (*medium confidence*); evidence in other regions is limited. {11.7.2, 11.7.3}.

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Compound Events, Including Dry/Hot Events, Fire Weather, Compound Flooding, and Concurrent Extremes

The probability of compound events has *likely* increased in the past due to human-induced climate change and will *likely* continue to increase with further global warming. Concurrent heatwaves and droughts have become more frequent, and this trend will continue with higher global warming (*high confidence*). Fire weather conditions (compound hot, dry and windy events) have become more probable in some regions (*medium confidence*) and there is *high confidence* that they will become more frequent in some regions at higher levels of global warming.

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Statements in the Executive Summary

Compound Events, Including Dry/Hot Events, Fire Weather, Compound Flooding, and Concurrent Extremes

The probability of compound events has *likely* increased in the past due to human-induced climate change and will *likely* continue to increase with further global warming. Concurrent heatwaves and droughts have become more frequent, and this trend will continue with higher global warming (*high confidence*). Fire weather conditions (compound hot, dry and windy events) have become more probable in some regions (*medium confidence*) and there is *high confidence* that they will become more frequent in some regions at higher levels of global warming. The probability of compound flooding (storm surge, extreme rainfall and/or river flow) has increased in some locations (*medium confidence*), and will continue to increase due to sea level rise and increases in heavy precipitation, including changes in precipitation intensity associated with tropical cyclones (*high confidence*). The land area affected by concurrent extremes has increased (*high confidence*). Concurrent extreme events at different locations, but possibly affecting similar sectors (e.g., critical crop-producing areas for global food supply) in different regions, will become more frequent with increasing global warming, in particular above 2°C of global warming (*high confidence*). {11.8, Box 11.2, Box 11.4}.

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Klimaänderung II

Klausur

Mittwoch, den 27. Juli 2022, zwischen 16:30 und 18:30 Uhr
Raum C 112 (Theresienstr. 41)

DLR