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The many possible climates from the Paris Agreement's aim of 1.5 °C warming

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Paris Agreement's aim of 1.5°C warming may result in many possible climates – SUPPLEMENTARY INFORMATION

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Supplementary Text 1: Projections of regional changes in climate extremes based on given changes in global temperatures

The computation of regional climate extreme indices based on given changes in global temperature (dTglob) in Table 1 and Figs. 2-3 follows the approach of Seneviratne et al (2016) and Wartenburger et al. (2017). This section provides additional background information compared to Box 1. The considered climate extremes indicators include the warming of the minimum annual night-time temperature (TNn) in the Arctic land [°C], the warming of the maximum annual day-time temperature (TXx) in the contiguous United States [°C], TXx warming in Central Brazil [°C], (soil moisture) drying in the Mediterranean region [in units of standard deviations of pre-industrial climate variability], and increases in heavy precipitation events based on annual maximum consecutive 5-day precipitation (Rx5day) in Southern Asia [%]). The definition of the geographical domains is provided in Seneviratne et al. (2016). The estimates are derived from CMIP5 simulations for 26 climate models and all four Representative Concentration Pathways (RCP) scenarios, i.e. RCP2.6, RCP4.0, RCP6.0 and RCP8.5, as well as historical simulations (see Suppl. Table S3 for list of analysed simulations). As noted in Box 1 of the main article, the values are computed based on decadal averages of 26 CMIP5 global climate model simulations (see Supplementary Table S3). Decades corresponding to a 1.5°C or 2°C warming are those in which the last year of the decade reaches this temperature, consistent with previous publications (IPCC 2013, Seneviratne et al. 2016, Wartenburger et al. 2017).

Supplementary Table S1: Description of different worlds based on scenarios considered compatible with 1.5°C and 2°C warming in the 5th assessment report of IPCC (Clarke et al. 2014, Rogelj et al. 2015), including projections of changes in regional climate associated with resulting global temperature levels derived following previous studies (Seneviratne et al. 2016, Wartenburger et al. 2017).

		SCEN_1p5C Emissions pathways currently considered in line with keeping warming below 1.5°C in 2100 with 66% chance (allowing for a higher peak in temperature earlier)		SCEN_2C Emissions pathways currently considered in line with keeping warming below 2°C during the entire 21st century with 66% chance	
		"probable" (66th percentile) outcome[a]	"worst-case" 10% (90th percentile) outcome[b]	"probable" (66th percentile) outcome[a]	"worst-case" 10% (90th percentile) outcome[b]
General characteristics of pathway	**Overshoot 1.5°C in 21st century with >50% likelihood[c]**	**Yes (8/8)**	**Yes (8/8)**	**Yes (60/60)**	**Yes (60/60)**
	Overshoot 2°C in 21st century with >50% likelihood	**No (0/8)**	**Yes (4/8)**	**No (0/60)**	**Yes (60/60)**
	Cumulative CO_2 emissions up to peak warming (relative to 2016)[d]	510 (490, 560)	470 (410, 520)	930 (790, 1050)	900 (750, 1040)
	Cumulative CO_2 emissions up to 2100 (relative to 2016)[d] [$GtCO_2$]	-40 (-100, 10)		850 (520, 1000)	
	Global GHG emissions in 2030[d] [$GtCO_2$ y^{-1}]	19 (17, 21)		28 (23, 32)	
	Years of global net zero CO_2 emissions[d]	2061 (2061, 2063)		2084 (2079, 2086)	
Possible climate range at peak warming (reg+glob)	**Global mean temperature anomaly at peak warming [°C]**	**1.65°C (1.61, 1.68°C)**	**2.01°C (1.95, 2.03°C)**	**1.90°C (1.86, 1.95°C)**	**2.35°C (2.29, 2.48°C)**
	Warming in the Arctic[e] (TNn[f]) [°C]	4.75 °C (4.09, 5.44)	5.90 °C (4.97, 6.85)	5.63 °C (4.68, 6.59)	6.97 °C (6.13, 8.38)
	Warming in the contiguous United States[e] (TXx[f]) [°C]	2.39 °C (1.90, 2.84)	2.97 °C (2.36, 3.40)	2.77 °C (2.20, 3.30)	3.51 °C (3.05, 4.11)
	Warming in Central Brazil[e] (TXx[f]) [°C]	2.55 °C (2.12, 2.97)	3.12 °C (2.66, 3.76)	2.96 °C (2.58, 3.55)	3.66 °C (3.31, 4.21)
	Drying in the Mediterranean region[e] [std[f]] (-1: dry; -2: severely dry; -3: very severely dry)	-1.00 (-2.12, -0.39)	-1.25 (-2.21, -0.51)	-1.11 (-2.18, -0.51)	-1.36 (-2.93, -0.69)
	Increase in heavy precipitation events[f] in Southern Asia[e] [%]	9.78 % (6.52, 13.63)	11.56 % (7.04, 18.50)	10.27 % (6.50, 17.40)	16.74 % (9.60, 23.44)
Possible climate range in 2100 (reg+glob)	**Global mean temperature warming in 2100 [°C]**	**1.41°C (1.39—1.43°C)**	**1.84°C (1.81—1.90°C)**	**1.84°C (1.76—1.89°C)**	**2.30°C (2.21—2.46°C)**
	Warming in the Arctic[g] (TNn[f]) [°C]	4.07 °C (3.53, 4.72)	5.37 °C (4.60, 6.40)	5.37 °C (4.46, 6.38)	6.86 °C (5.83, 8.24)
	Warming in the contiguous United States[g] (TXx[f]) [°C]	2.00 °C (1.60, 2.48)	2.62 °C (2.17, 3.23)	2.62 °C (2.07, 3.24)	3.37 °C (2.88, 4.03)
	Warming in Central Brazil[g] (TXx[f]) [°C]	2.20 °C (1.95, 2.58)	2.88 °C (2.46, 3.48)	2.88 °C (2.43, 3.47)	3.57 °C (3.20, 4.18)
	Drying in the Mediterranean region[g] [std[f]]	-0.96 (-1.89, -0.28)	-1.24 (-2.27, -0.45)	-1.24 (-2.42, -0.46)	-1.38 (-2.79, -0.67)
	Increase in heavy precipitation events[f] in Southern Asia[g] [%]	7.83 % (4.20, 12.00)	10.19 % (6.34, 16.67)	10.19 % (6.46, 16.64)	15.47 % (8.72, 22.98)

[a] 66th percentile estimates for global temperature (i.e. 66% likelihood of being at or below values)
[b] 90th percentile estimates for global temperature (i.e. 10% likelihood of being at or above values)
[c] All 1.5°C scenarios from AR5 include a substantial probability of overshooting above 1.5°C global warming before returning to 1.5°C
[d] The values indicate the median and the interquartile range in parenthesis (25th percentile and 75th percentile)
[e] The regional projections in these rows provide the range [median (q25, q75)] associated with the *median* global temperature outcomes of the considered mitigation scenarios at *peak warming* (see Suppl. Text 1 for details).
[f] TNn: annual minimum night-time temperature; TXx: annual maximum day-time temperature; std: drying of soil moisture expressed in units of standard deviations of pre-industrial climate (1861-1880) variability; Rx5day: annual maximum consecutive 5-day precipitation (see Suppl. Text 1 for details)
[g] Same as footnote e, but for the regional responses associated with the *median* global temperature outcomes of the considered mitigation scenarios *by 2100* (see Suppl. Text 1 for details).

Supplementary Table S2: Description of different worlds based on scenarios currently considered compatible with 1.5°C and 2°C warming (Rogelj et al. 2018), including projections of changes in regional climate associated with resulting global temperature levels derived following previous studies (Seneviratne et al. 2016, Wartenburger et al. 2017). The results are provided for the 50th percentile (median) outcome of the scenarios in addition to the 66th and 90th percentile.

		SCEN_1p5C Emissions pathways currently considered in line with keeping warming below 1.5°C in 2100 with 66% chance (allowing for a higher peak in temperature earlier)			SCEN_2C Emissions pathways currently considered in line with keeping warming below 2°C during the entire 21st century with 66% chance		
		"as likely as not" (50th percentile) outcome[a]	"probable" (66th percentile) outcome[b]	"worst-case" 10% (90th percentile) outcome[c]	**"as likely as not" (50th percentile) outcome[a]**	"probable" (66th percentile) outcome[b]	"worst-case" 10% (90th percentile) outcome[c]
General characteristics of pathway	**Overshoot 1.5°C in 21st century with >50% likelihood[d]**	**Yes (13/13)**	**Yes (13/13)**	**Yes (13/13)**	**Yes (10/10)**	**Yes (10/10)**	**Yes (10/10)**
	Overshoot 2°C in 21st century with >50% likelihood	**No (0/13)**	**No (0/13)**	**Yes (10/13)**	**No (0/10)**	**No (0/10)**	**Yes (10/10)**
	Cumulative CO_2 emissions up to peak warming (relative to 2016)[e]	**710 (630,770)**	720 (650, 750)	690 (650, 710)	**1050 (1000, 1110)**	1050(1020, 1140)	1040 (930, 1140)
	Cumulative CO_2 emissions up to 2100 (relative to 2016)[e] [$GtCO_2$]	320 (200, 340)			1030 (910, 1140)		
	Global GHG emissions in 2030[e] [$GtCO_2\ y^{-1}$]	22 (19, 31)			28 (24, 30)		
	Years of global net zero CO_2 emissions[e]	2070 (2067, 2074)			2088 (2085, 2092)		
Possible climate range at peak warming (reg+glob)	**Global mean temperature anomaly at peak warming [°C]**	**1.6°C (1.52-1.66)**	**1.75°C (1.65-1.81)**	**2.13°C (2.0- 2.2)**	**1.74°C (1.73-1.76)**	**1.93°C (1.9-1.94°C)**	**2.44°C (2.43-2.46°C)**
	Warming in the Arctic[f] (TNn[g]) [°C]	**4.66°C (4.05, 5.25)**	4.75 °C (4.09, 5.44)	5.90 °C (4.97, 6.85)	**5.01°C (4.45, 5.58)**	5.63 °C (4.68, 6.59)	6.97 °C (6.13, 8.38)
	Warming in the contiguous United States[f] (TXx[g]) [°C]	**2.28°C (1.91, 2.67)**	2.39 °C (1.90, 2.84)	2.97 °C (2.36, 3.40)	**2.53°C (2.03, 2.95)**	2.77 °C (2.20, 3.30)	3.51 °C (3.05, 4.11)
	Warming in Central Brazil[e] (TXx[f]) [°C]	**2.49°C (2.12, 2.86)**	2.55 °C (2.12, 2.97)	3.12 °C (2.66, 3.76)	**2.72°C (2.33, 3.19)**	2.96 °C (2.58, 3.55)	3.66 °C (3.31, 4.21)
	Drying in the Mediterranean region[f] [std[g]] (-1: dry; -2: severely dry; -3: very severely dry)	**-0.94 (-2.10, -0.38)**	-1.00 (-2.12, -0.39)	-1.25 (-2.21, -0.51)	**-1.26 (-2.35, -0.43)**	-1.11 (-2.18, -0.51)	-1.36 (-2.93, -0.69)
	Increase in heavy precipitation events[g] in Southern Asia[f] [%]	**9.22% (6.26, 13.84)**	9.78 % (6.52, 13.63)	11.56 % (7.04, 18.50)	**9.83% (7.03, 14.87)**	10.27 % (6.50, 17.40)	16.74 % (9.60, 23.44)
Possible climate range in 2100 (reg+glob)	**Global mean temperature warming in 2100 [°C]**	**1.29°C (1.27— 1.31)**	**1.44°C (1.44—1.48)**	**1.88°C (1.85—1.93)**	**1.69°C (1.68—1.7)**	**1.89°C (1.88—1.91°C)**	**2.43°C (2.42—2.46°C)**
	Warming in the Arctic[h] (TNn[g]) [°C]	**3.78°C (3.29, 4.25)**	4.07 °C (3.53, 4.72)	5.37 °C (4.60, 6.40)	**4.90°C (4.30, 5.46)**	5.37 °C (4.46, 6.38)	6.86 °C (5.83, 8.24)
	Warming in the contiguous United States[h] (TXx[g]) [°C]	**1.82°C (1.33, 2.22)**	2.00 °C (1.60, 2.48)	2.62 °C (2.17, 3.23)	**2.45°C (1.98, 2.87)**	2.62 °C (2.07, 3.24)	3.37 °C (2.88, 4.03)
	Warming in Central Brazil[h] (TXx[g]) [°C]	**2.06°C (1.80, 2.40)**	2.20 °C (1.95, 2.58)	2.88 °C (2.46, 3.48)	**2.63°C (2.27, 3.00)**	2.88 °C (2.43, 3.47)	3.57 °C (3.20, 4.18)
	Drying in the Mediterranean region[h] [std[g]]	**-0.72 (-1.84, -0.27)**	-0.96 (-1.89, -0.28)	-1.24 (-2.27, -0.45)	**-1.09 (-2.23, -0.40)**	-1.24 (-2.42, -0.46)	-1.38 (-2.79, -0.67)
	Increase in heavy precipitation events[f] in Southern Asia[h] [%]	**6.48% (3.08, 11.15)**	7.83 % (4.20, 12.00)	10.19 % (6.34, 16.67)	**9.82% (6.69, 13.86)**	10.19 % (6.46, 16.64)	15.47 % (8.72, 22.98)

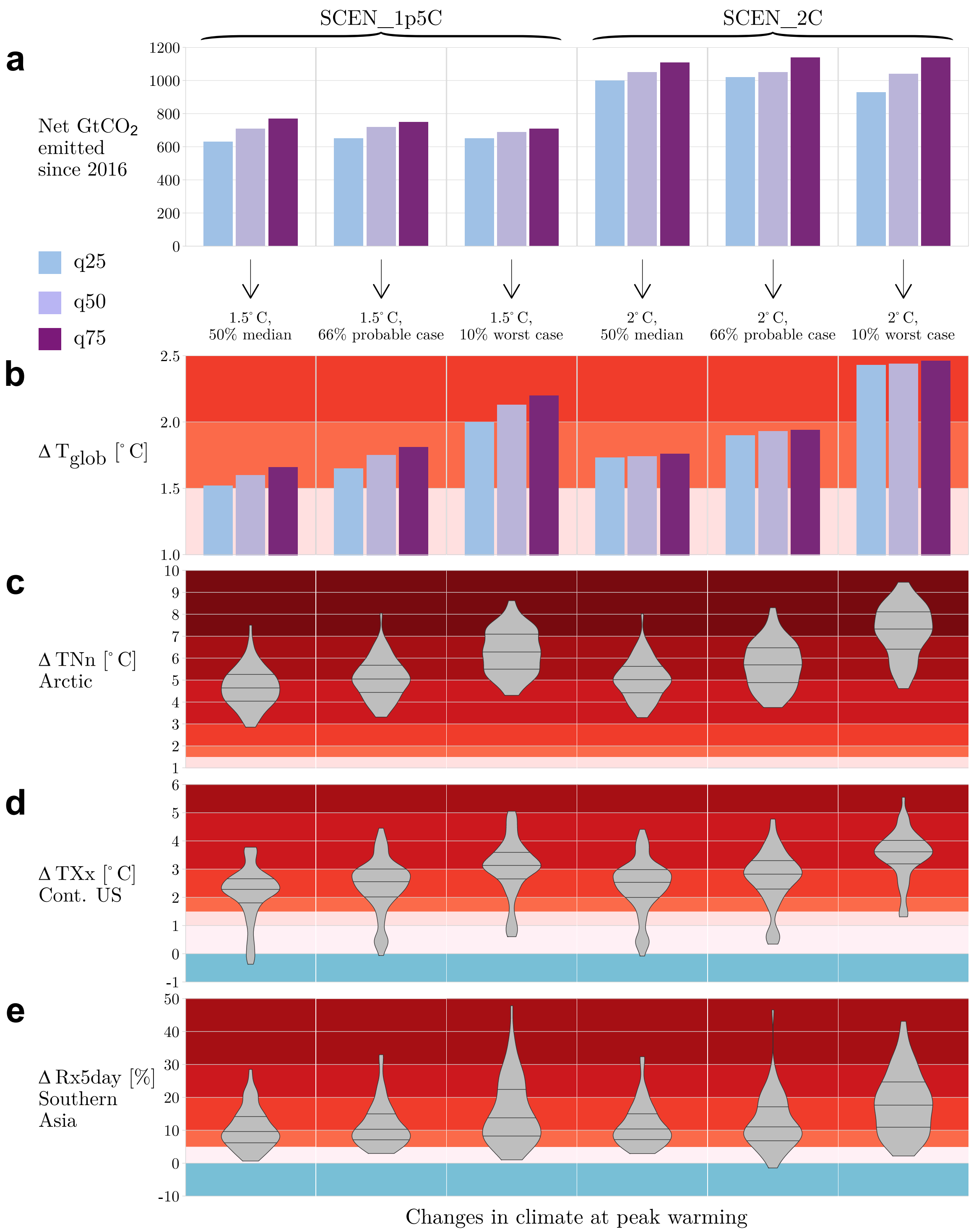
[a] 50th percentile (median) estimates for global temperature (i.e. as likely as not of being below or above values)
[b] 66th percentile estimates for global temperature (i.e. 66% likelihood of being at or below values)
[c] 90th percentile estimates for global temperature (i.e. 10% likelihood of being at or above values)
[d] All 1.5°C scenarios from AR5 include a substantial probability of overshooting above 1.5°C global warming before returning to 1.5°C
[e] The values indicate the median and the interquartile range in parenthesis (25th percentile and 75th percentile)
[f] The regional projections in these rows provide the range [median (q25, q75)] associated with the *median* global temperature outcomes of the considered mitigation scenarios at *peak warming* (see Suppl. Text 1 for details).

[g] TNn: annual minimum night-time temperature; TXx: annual maximum day-time temperature; std: drying of soil moisture expressed in units of standard deviations of pre-industrial climate (1861-1880) variability; Rx5day: annual maximum consecutive 5-day precipitation (see Suppl. Text 1 for details)

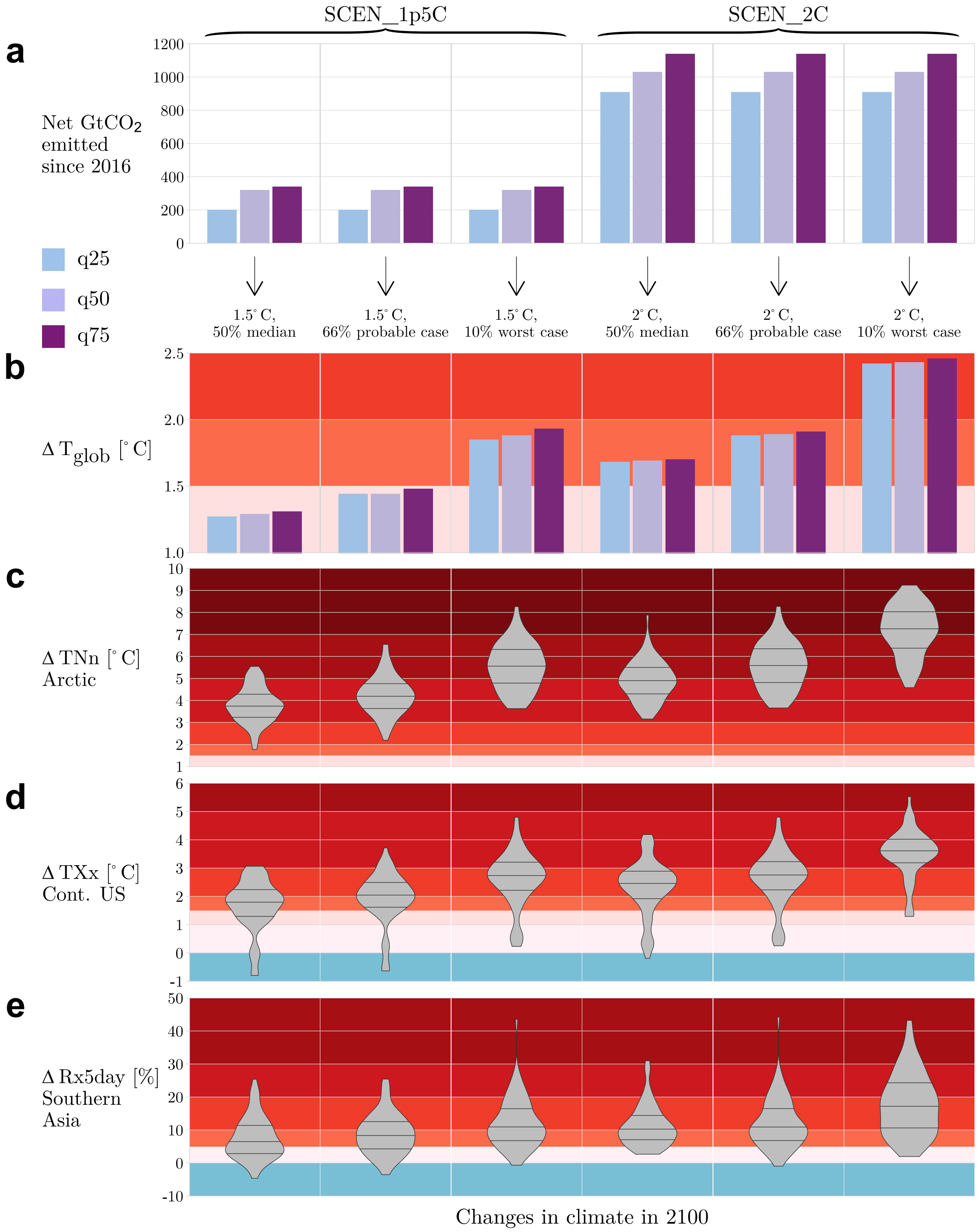
[h] Same as footnote f, but for the regional responses associated with the *median* global temperature outcomes of the considered mitigation scenarios *by 2100* (see Suppl. Text 1 for details).

Supplementary Table S3: List of 26 CMIP5 models used in the analysis of climate extremes (see Wartenburger et al. 2017 for more details).

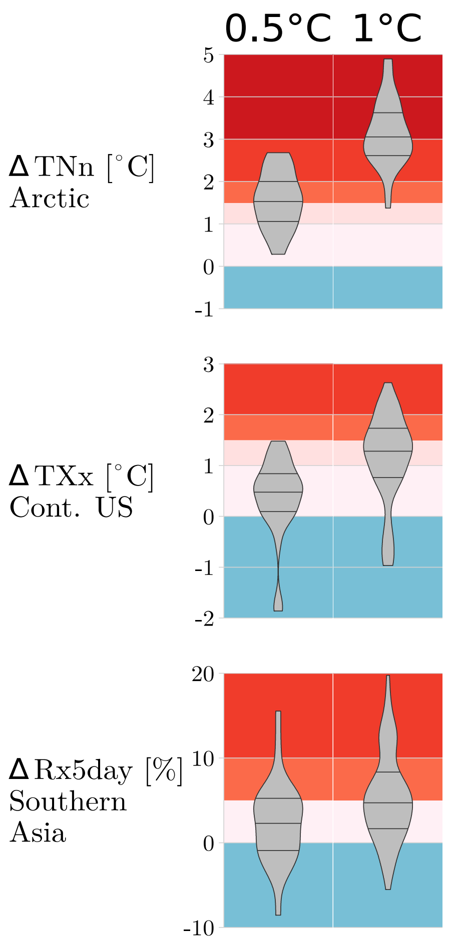
Model	Modelling Centre	Historical	RCP2.6	RCP4.5	RCP6.0	RCP8.5
ACCESS1-0	Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	x		x		x
bcc-csm1-1	Beijing Climate Center, China Meteorological Administration	x	x	x	x	x
bcc-csm1-1-m		x	x	x	x	x
CanESM2	Canadian Centre for Climate Modelling and Analysis	x	x	x		x
CCSM4	National Center for Atmospheric Research, USA	x		x	x	x
CMCC-CM	Centro Euro-Mediterraneo per i Cambiamenti Climatici, Italy	x		x		x
CMCC-CMS		x		x		x
CNRM-CM5	Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancées en Calcul Scientifique, France	x	x	x		x
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization / Queensland Climate Change Centre of Excellence, Australia	x	x	x	x	x
FGOALS-s2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	x	x	x	x	x
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory, USA	x	x		x	x
GFDL-ESM2G		x	x	x	x	x
GFDL-ESM2M		x	x	x	x	x
HadGEM2-CC	Met Office Hadley Centre, United Kingdom	x		x		x
HadGEM2-ES		x	x		x	x
inmcm4	Institute for Numerical Mathematics, Russia	x		x		x
IPSL-CM5A-LR	Institut Pierre-Simon Laplace, France	x	x	x	x	x
IPSL-CM5A-MR		x	x		x	x
IPSL-CM5B-LR		x		x		x
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	x	x	x	x	x
MIROC-ESM-CHEM		x	x	x	x	x
MIROC5		x	x	x	x	x
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	x	x	x		x
MPI-ESM-MR		x	x	x		x
MRI-CGCM3	Meteorological Research Institute, Japan	x	x	x	x	x
NorESM1-M	Norwegian Climate Centre	x	x	x	x	x



Supplementary Figure S1: Possible outcomes with respect to global temperature and regional climate anomalies from typical 1.5°C-warming and 2°C-warming compatible scenarios (Rogelj et al. 2018) at peak warming, including regional responses for median estimates (50th percentile, see Suppl. Table S2) of changes in global temperature. *(a) Net GtCO$_2$ emitted until time of peak warming relative to 2016 (including carbon dioxide removal from the atmosphere) in considered scenarios from Supplementary Table S2 (25thquantile (q25), median (q50), and 75th quantile (q75)). (b) Global mean temperature anomaly at peak warming (q25, q50, q75). (c-e): Regional climate anomalies at peak warming compared to the pre-industrial period corresponding to the median global warming of the 2nd row (full range associated with different regional responses within CMIP5 multi-model ensemble displayed as violin plot; the median and interquartile ranges are indicated with horizontal dark gray lines).*



Supplementary Figure S2: Possible outcomes with respect to global temperature and regional climate anomalies from typical 1.5°C-warming and 2°C-warming compatible scenarios (Rogelj et al. 2018) in 2100, including regional responses for median estimates (50th percentile, see Suppl. Table S2) of changes in global temperature. *(a) Net $GtCO_2$ emitted by 2100 relative to 2016 (including carbon dioxide removal from the atmosphere) in considered scenarios from Table 1 (25th quantile (q25), median (q50), and 75th quantile (q75)). (b) Global mean temperature anomaly in 2100 (q25, q50, q75). (c-e) Regional climate anomalies at peak warming compared to the pre-industrial period corresponding to the median global warming of the 2nd row (full range associated with different regional responses within CMIP5 multi-model ensemble displayed as violin plot; the median and interquartile ranges are indicated with horizontal dark gray lines).*



Supplementary Figure S3: Spread in regional changes in climate extremes for recent and present-day global mean warming (0.5°C, left, and 1°C global warming, right). The regional assessments are derived using the approach of Seneviratne et al. (2016) and Wartenburger et al. (2017) for changes in global temperature of 0.5°C and 1°C compared to pre-industrial conditions, based on historical simulations and climate change projections from 26 CMIP5 models (see Supplementary Text 1 and Supplementary Table S3). Present-day warming compared to the pre-industrial period is approximately equivalent to 1°C (Haustein et al. 2017). The estimates are provided for changes in climate extremes in three regions: the change in the annual minimum daily temperature (ΔTNn) in the Arctic land [°C], the changes in the annual maximum daily temperature (ΔTXx) in the contiguous United States [°C], and the increases in heavy precipitation events based on annual maximum consecutive 5-day precipitation (Rx5day) in Southern Asia [%] (see Supplementary Text 1 for more details). The full range associated with different regional responses within the CMIP5 multi-model ensemble is displayed as violin plot; the median and interquartile ranges are indicated with horizontal dark gray lines.

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