Recap from last lecture

- SSPs vs RCPs
- Paris agreement and 5 year NDC cycle
- IPCC issued every 5-8 years, yearly reports by UN and other organizations

General outline

	No.	Date	Topics	Deadlines / tentative
Basics	1.	11.09.2025	Introduction to the climate system	Questionnaire (not graded)
	2.	18.09.2025	Climate System, Radiation	
	3.	25.09.2025	Radiation, Earth's Energy balance, Greenhouse effect	launch of first assignment
	4.	02.10.2025	Aerosols & clouds, Radiative Forcing	Launch of poster project
	5.	09.10.2025	Feedback mechanisms, Climate Sensitivity	
	6.	16.10.2025	Paleoclimate	submission of Poster proposal (graded)
Present and future Climate change	7.	30.10.2025	Climate variability, Introduction to IPCC	
	8.	06.11.2025	Current state of climate, IPCC – report, Paris Agreement, Climate scenarios (RCPs, SSPs)	
	9.	13.11.2025	Emissions Gap, 1.5 vs 2.0°C vs warmer, Tipping elements, Extreme Events	submission of Poster draft (graded)
	10.	20.11.2025	Extreme Events, Carbon budget	
	11.	27.11.2025	Carbon budget, Metrics	submission of assignment (graded)
	12.	04.12.2025	Polar climate change	
Actions	13.	11.12.2025	Mitigation measures	Poster Conference (graded)
	14.	18.12.2025	Climate engineering, questions and answers session	fill in Questionnaire in exercises (not graded)

Paris Agreement 2015

*"The **Paris Agreement** central aim is to [...] keep global temperature rise [...] well below 2°C above pre-industrial levels and to pursue efforts to limit the [...] increase [...] to 1.5 °C."*

https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

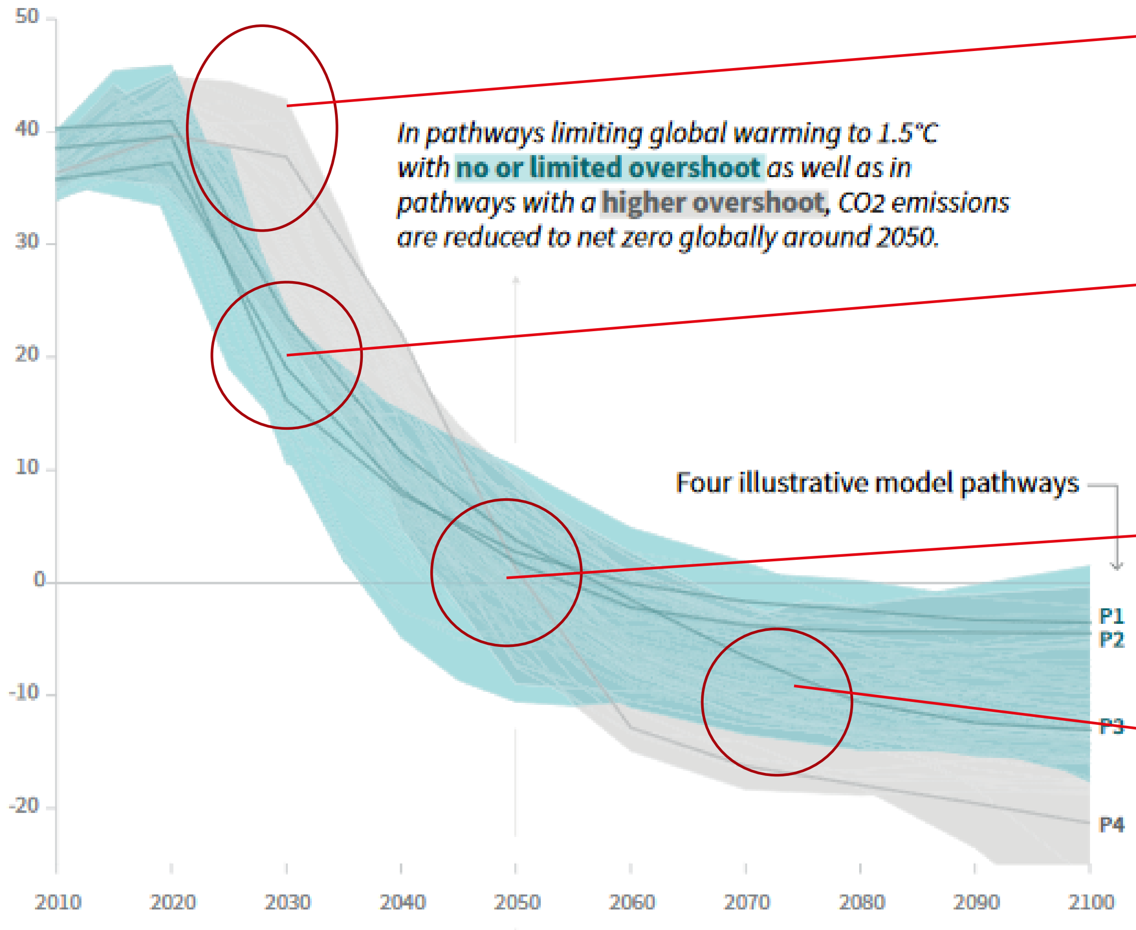
In 2021, at the Conference of the Parties (COP) in Glasgow, the international community agreed to strive for a maximum warming of 1.5 °C.

https://unfccc.int/process-and-meetings/the-paris-agreement/the-glasgow-climate-pact-key-outcomes-from-cop26

Reducing emissions for 1.5°C

Global total net CO_2 emissions

Billion tonnes of CO_2/yr

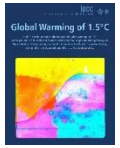


«overshoot», followed by steeper reduction

In 2030 only 50 % of emissions compared to 2010

Net-zero at the latest in 2040-2050

«negative emissions» about 25 % of present-day emissions!



Timing of net zero CO_2
Line widths depict the 5-95th percentile and the 25-75th percentile of scenarios

Pathways limiting global warming to 1.5°C with no or limited overshoot

Pathways with higher overshoot

Pathways limiting global warming below 2°C (Not shown above)

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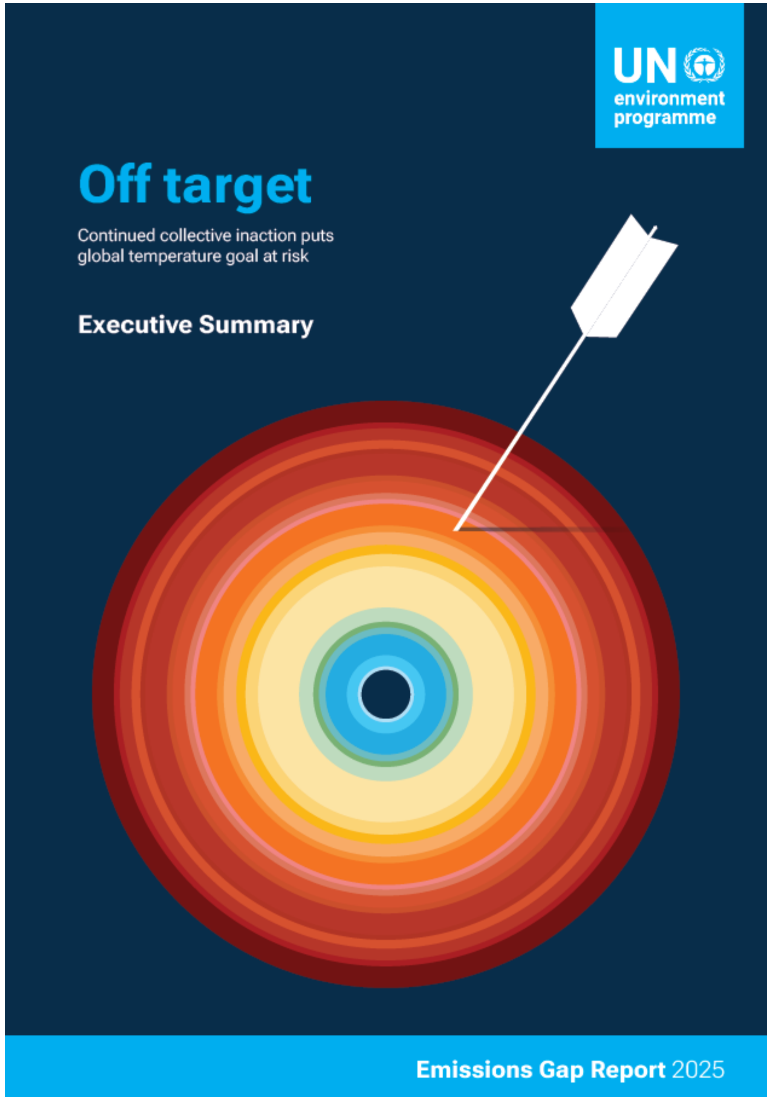
Emissions gap report 2025



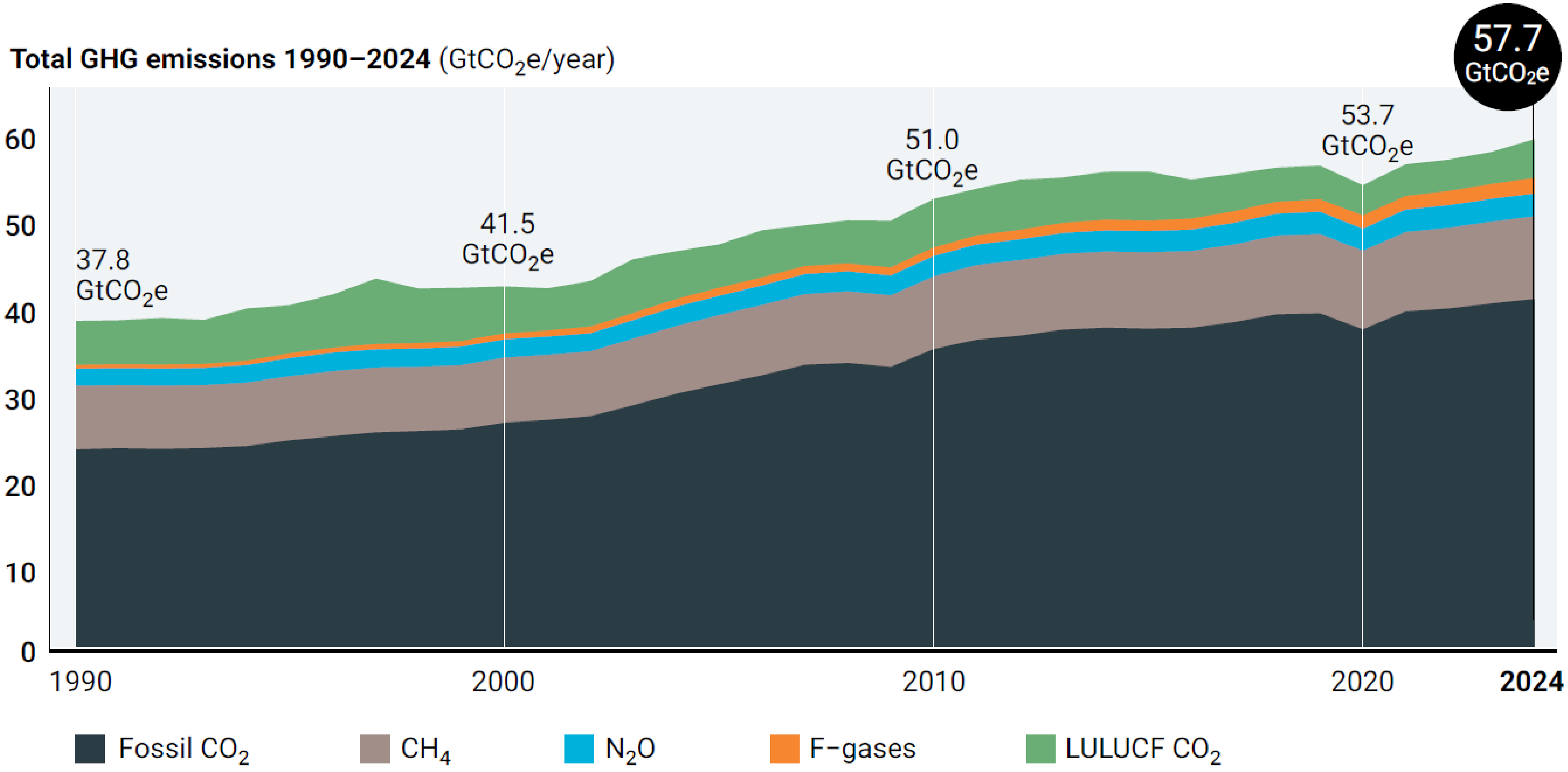
- **Another year of broken records – global GHG emissions reached 57.7 GtCO^{2}e in 2024, a 2.3 per cent increase from 2023 levels**

- despite the key role of fossil fuels in driving total emissions, deforestation and land-use change was decisive for the rapid increase in 2024 emissions (figure ES.2). Global net land use, land-use change and forestry (LULUCF) CO_2 emissions increased by 21 per cent in 2024, and were responsible for 53 per cent of the overall increase in global GHG emissions.

- Fossil CO_2 increased by 1.1 per cent and was responsible for 36 per cent of the increase in global GHG emissions.

Evolution of emissions

Figure ES.1 Total net anthropogenic GHG emissions, 1990–2024



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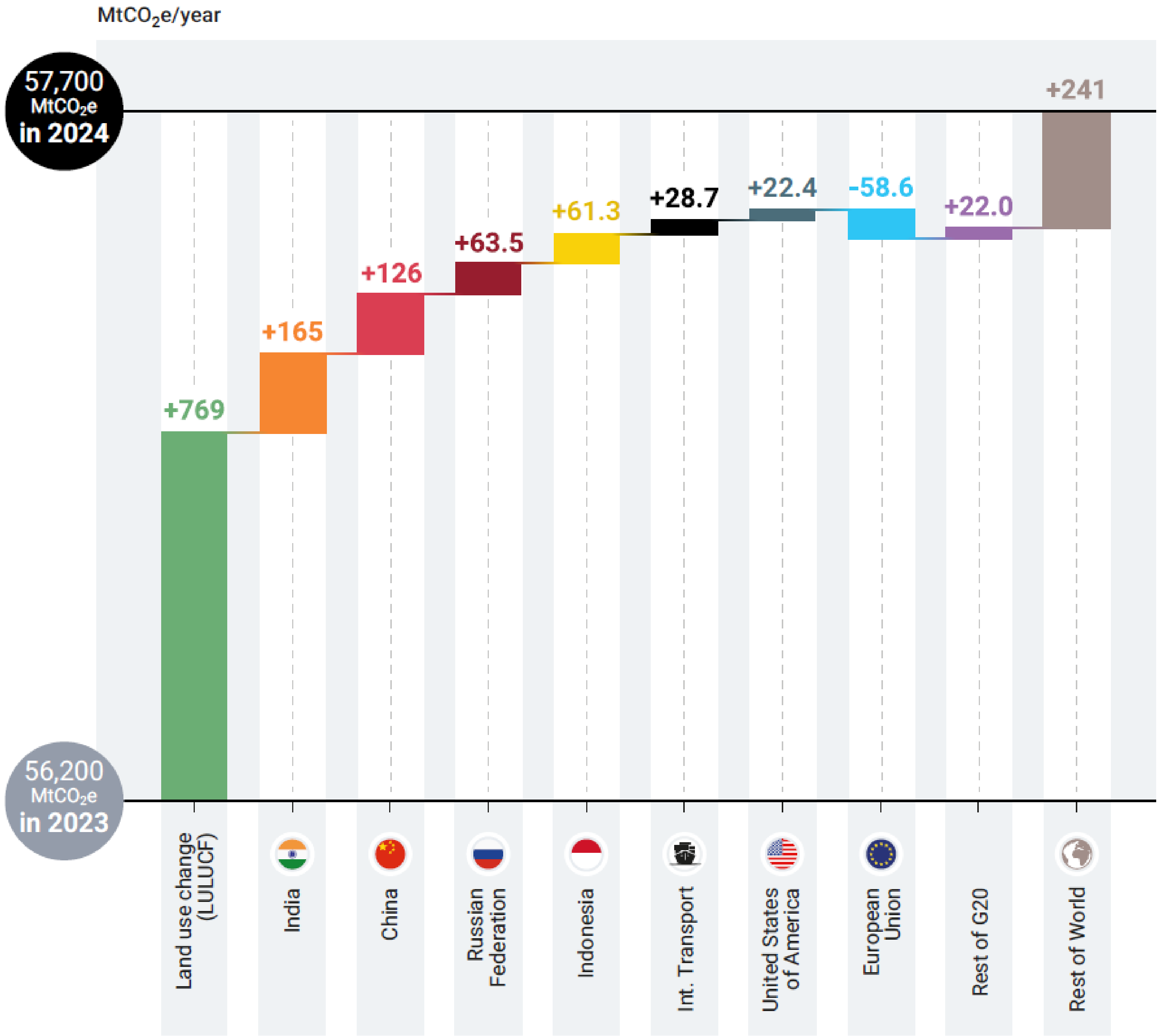
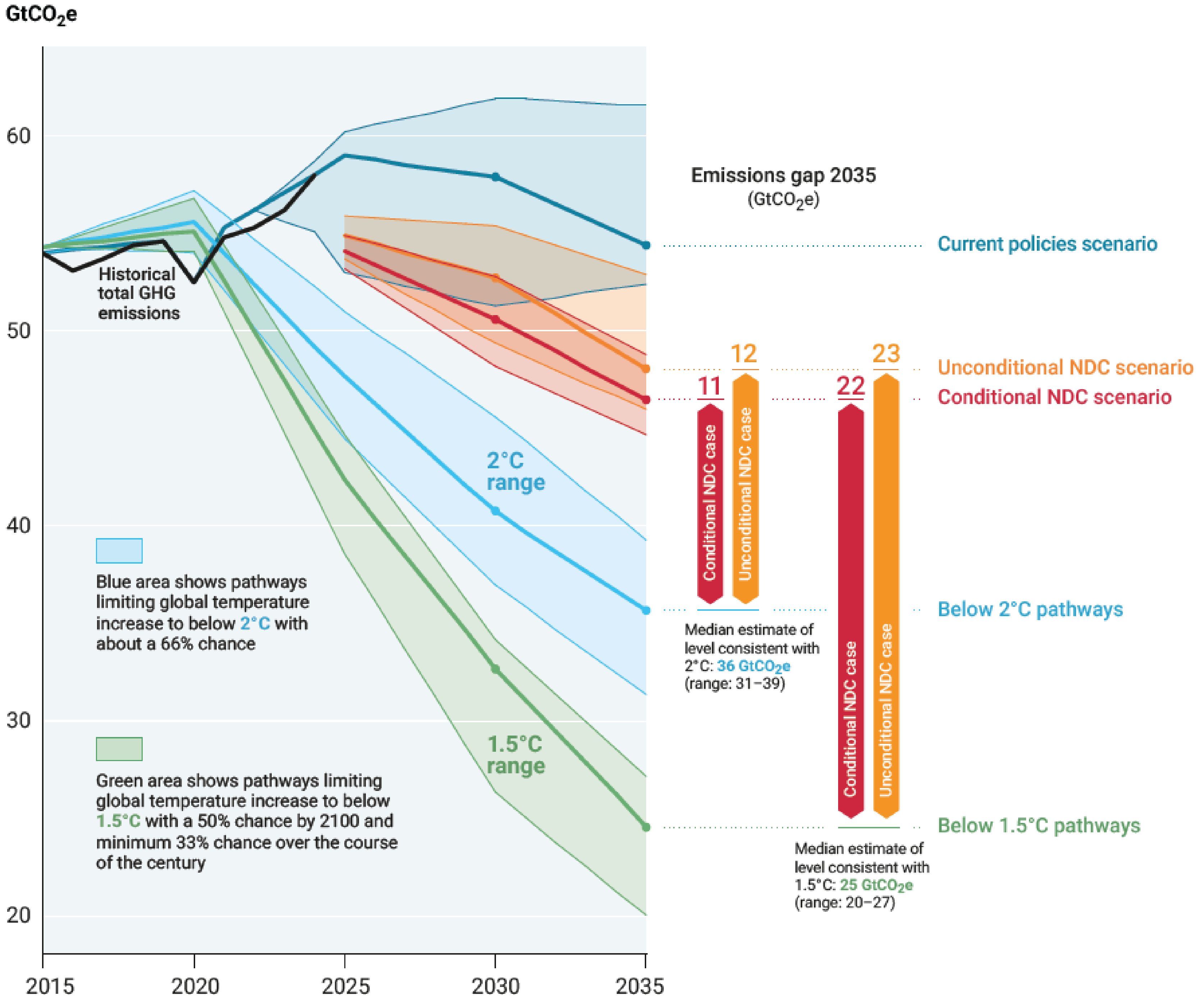
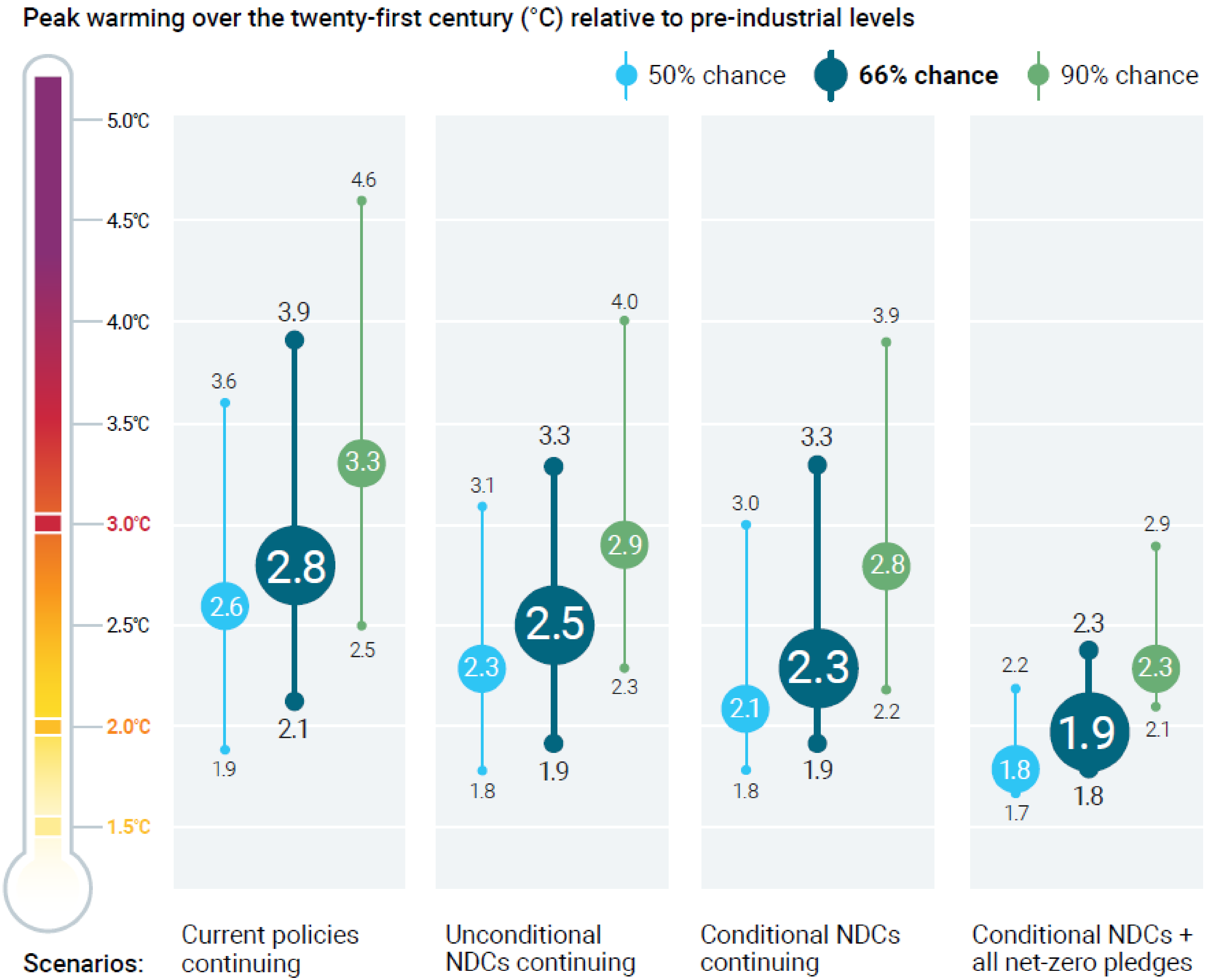
Change from 2024





- The new NDCs and policy updates of the G20 members lower expected GHG emissions in 2035, but reductions are relatively small and surrounded by significant uncertainty
- Seven G20 members are on track to achieving their NDC targets, but few are on a clear trajectory towards their net-zero emission pledges



Temperature projections are only slightly lower than last year and reiterate that immediate mitigation matters

- A continuation of the mitigation effort implied by current policies only limits warming below 2.8°C (range: 2.1–3.9) over the century, with a 66 per cent chance.
- This level of warming would be reduced to 2.5°C (range: 1.9–3.3) if unconditional NDCs are fully implemented by 2035 and similar efforts continue.
- Even with efforts sufficient to meet the conditional NDCs in full, warming would only be kept below 2.3°C (range 1.9–3.3) with at least a 66 per cent chance.
- By 2050, the central warming projections for these scenarios see global warming surpassing 1.5°C by several tenths of a degree, leaving the world with a 21–33 per cent chance that warming will already exceed 2°C by then.

1.5°C?

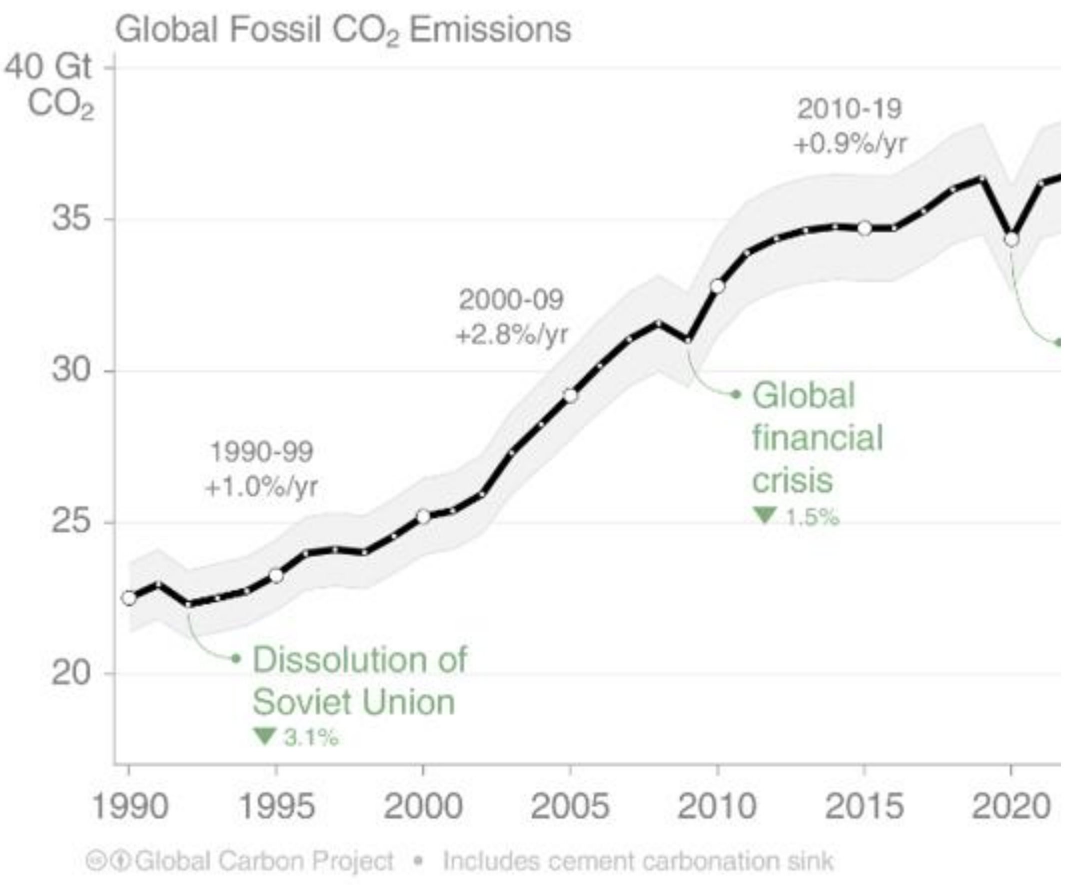
These projections highlight the potential to reduce warming significantly through immediate mitigation action. However, they also underline the uncomfortable truth that surpassing 1.5°C is increasingly near, and that the risk of even higher levels of warming is rising fast.

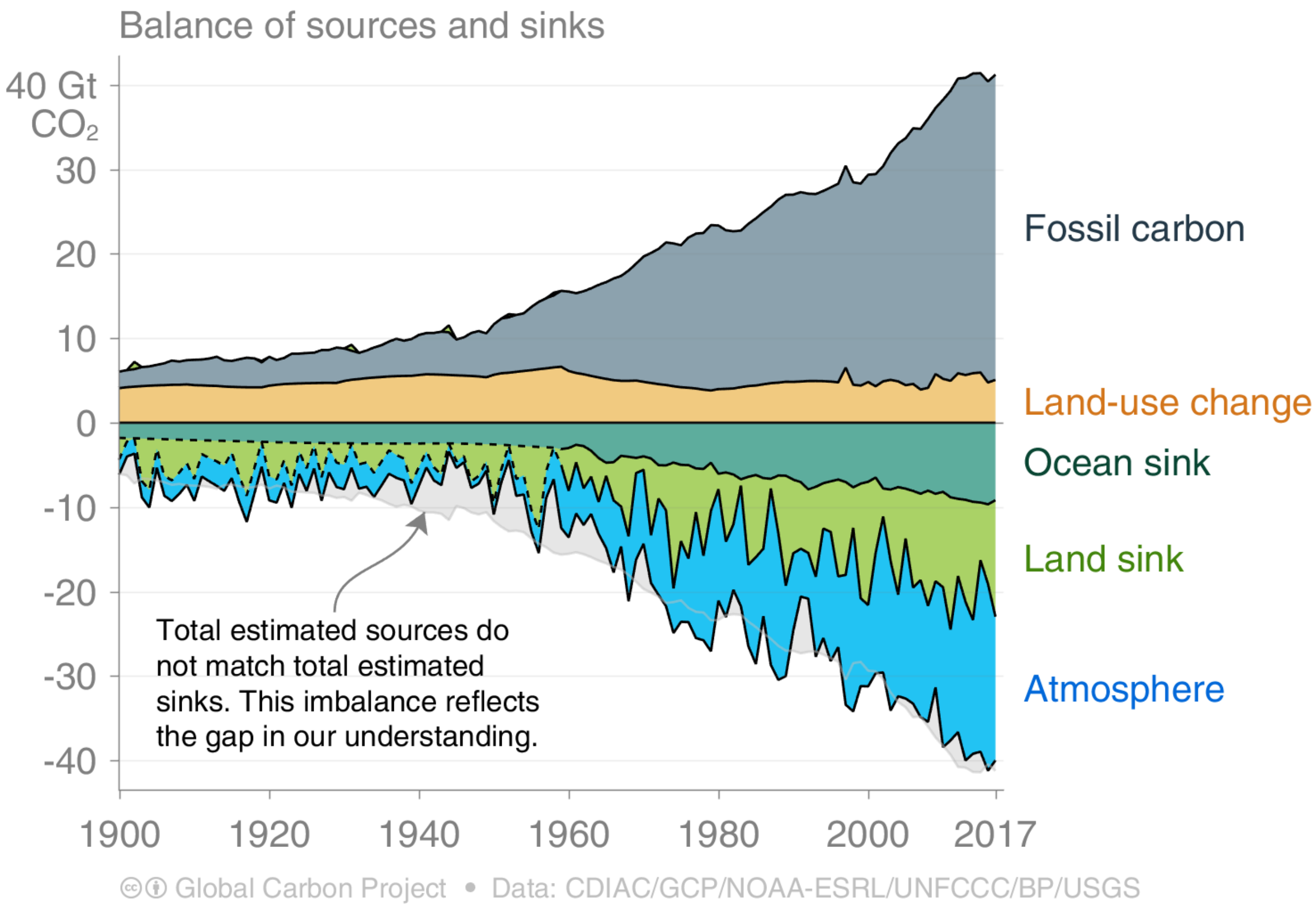
Likelihood of limiting warming below a specific temperature limit (%) over the twenty-first century

	Current policies continuing	Unconditional NDCs continuing	Conditional NDCs continuing	Conditional NDCs + all net-zero pledges
below 3°C	80% (16–99%)	92% (44–100%)	95% (50–100%)	100% (94–100%)
below 2°C	8% (0–56%)	25% (0–74%)	37% (1–77%)	78% (36–85%)
below 1.5°C	0% (0–7%)	1% (0–16%)	3% (0–18%)	21% (2–27%)

Scenarios: Current policies continuing; Unconditional NDCs continuing; Conditional NDCs continuing; Conditional NDCs + all net-zero pledges

Annual CO_2 emissions





Fate of anthropogenic CO_2 emissions (2013–2022)

Sources = Sinks

35.3 $GtCO_2$/yr
88%

12%
4.7 $GtCO_2$/yr

18.9 $GtCO_2$/yr
47%

31%
12.3 $GtCO_2$/yr

26%
10.4 $GtCO_2$/yr

Budget Imbalance: 4%
(the difference between estimated sources & sinks) -1.6 $GtCO_2$/yr

https://globalcarbonbudget.org/carbonbudget2023/

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Impact on Nature

Droughts in the Amazon

Boreal wild fires

Climate and Biodiversity crises are the same.

Nature as carbon sink

- Natural ecosystems sequester carbon that is released by human activities.
- As nature is depleted, the capacity to sequester and store carbon decreases as well.
- The carbon sequestration service of Nature is desperately needed for humanity to meet the Paris Agreement goal.
- Tropical rain forests are losing their ability to act as carbon sink:
  - Congo basin – sink
  - Amazon rain forest – not a sink at the moment
  - South-East Asian rain forest – source

- Belém COP30 – Tropical Forest Forever Facility (TFFF)
  - Proposal of Brasil to finance the stop of deforestation and degradation of moist broadleaf forests
  - Result-based payment to countries
  - Aims for 125 billion $ fund (private-public)
  - Rainforest countries would get 4$ for every hectare of intact forest, for each hectar deforested a deduction of $400 is made
  - 20 % of income goes to indigeneous peoples

Forest carbon sink

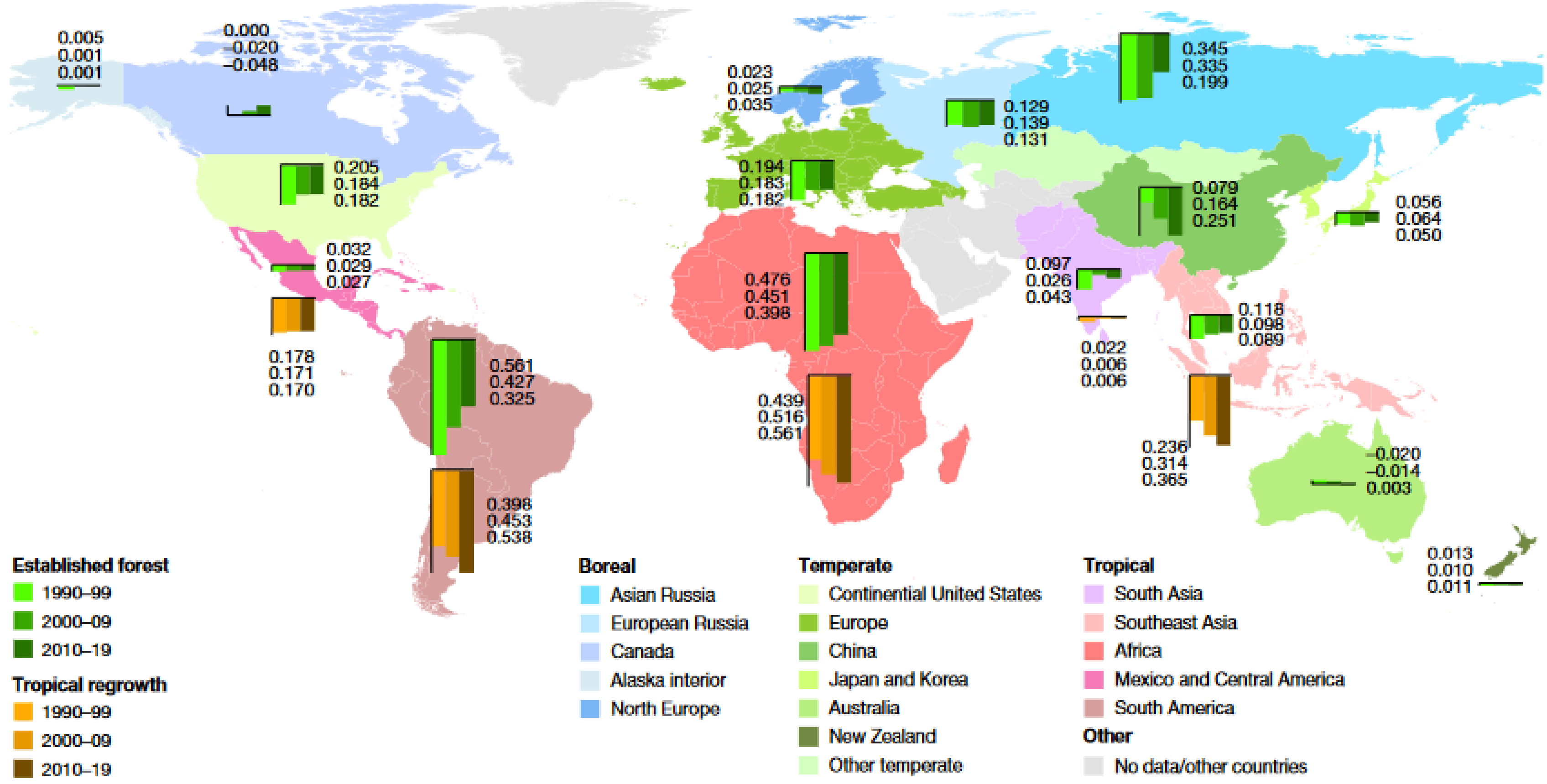


Fig. 1 | Carbon sinks and sources in the world's forests through the decades. Green bars represent established forests (boreal, temperate and tropical intact forests) and brown bars represent tropical regrowth forests. All values are in Pg C yr^{-1}. Positive values (with downward bars) indicate carbon sinks and negative values (upward bars) show carbon sources. Detailed uncertainties of sinks and sources are shown in Extended Data Table 3. We grouped a few regions and countries together so there are fewer categories to prevent the graphic getting too cluttered. These include: Europe (Europe temperate and other Europe); Japan and Korea; South Asia (India and other South Asia); and Mexico and Central America (Extended Data Table 3).

We found that the carbon sink in global forests was steady, at 3.6 ± 0.4 Pg C yr −1 in the 1990s and 2000s, and 3.5 ± 0.4 Pg C yr −1 in the 2010s. Despite this global stability, our analysis revealed some major biome-level changes. Carbon sinks have increased in temperate (+30 ± 5%) and tropical regrowth (+29 ± 8%) forests owing to increases in forest area, but they decreased in boreal (−36 ± 6%) and tropical intact (−31 ± 7%) forests, as a result of intensified disturbances and losses in intact forest area, respectively. he global forest sink is equivalent to almost half of fossil-fuel emissions (7.8 ± 0.4 Pg C yr −1 in 1990–2019). However, two-thirds of the benefit from the sink has been negated by tropical deforestation (2.2 ± 0.5 Pg C yr −1 in 1990–2019). Although the global forest sink has endured undiminished for three decades, despite regional variations, it could be weakened by ageing forests, continuing deforestation and further intensification of disturbance regimes1

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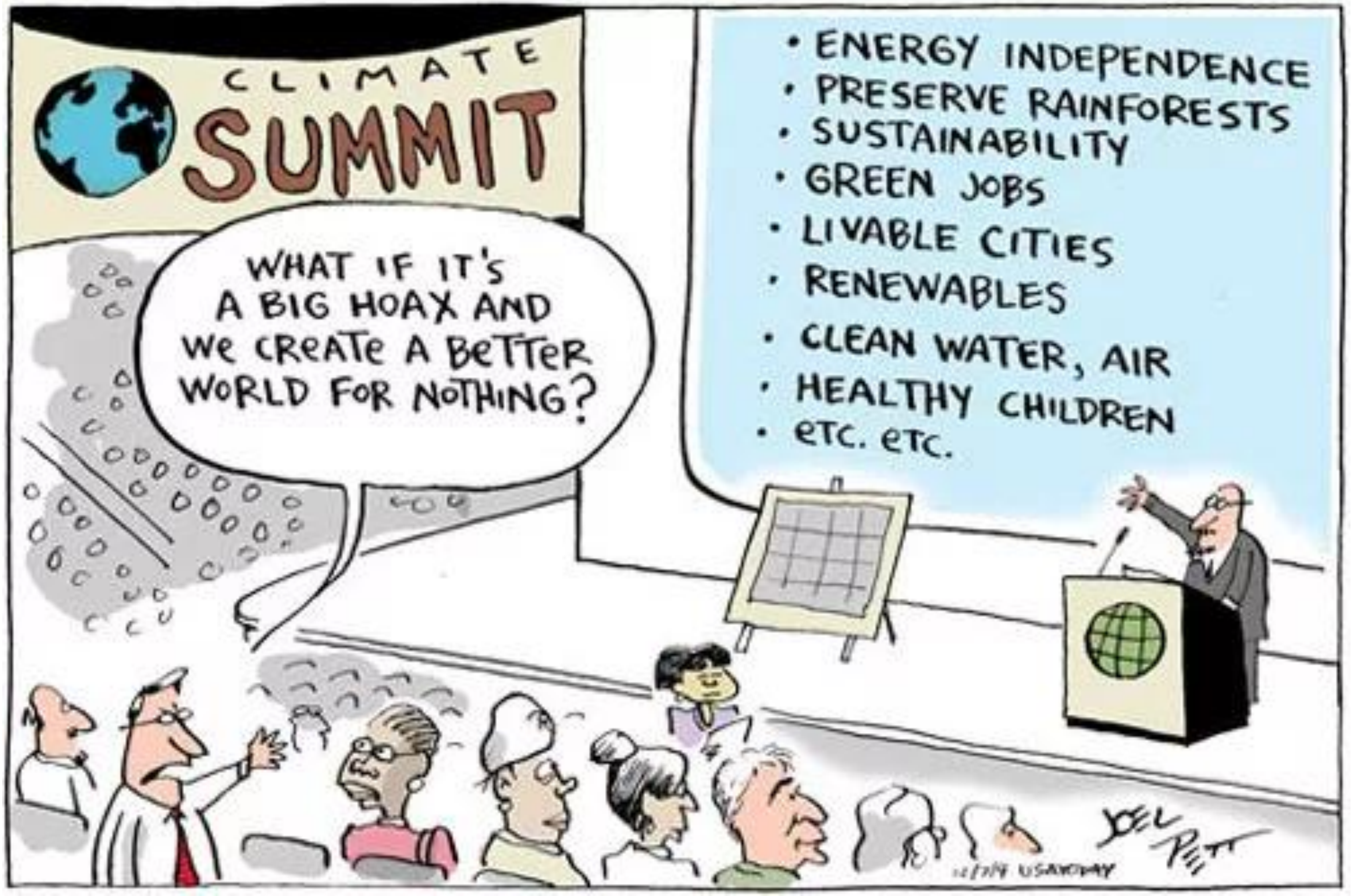
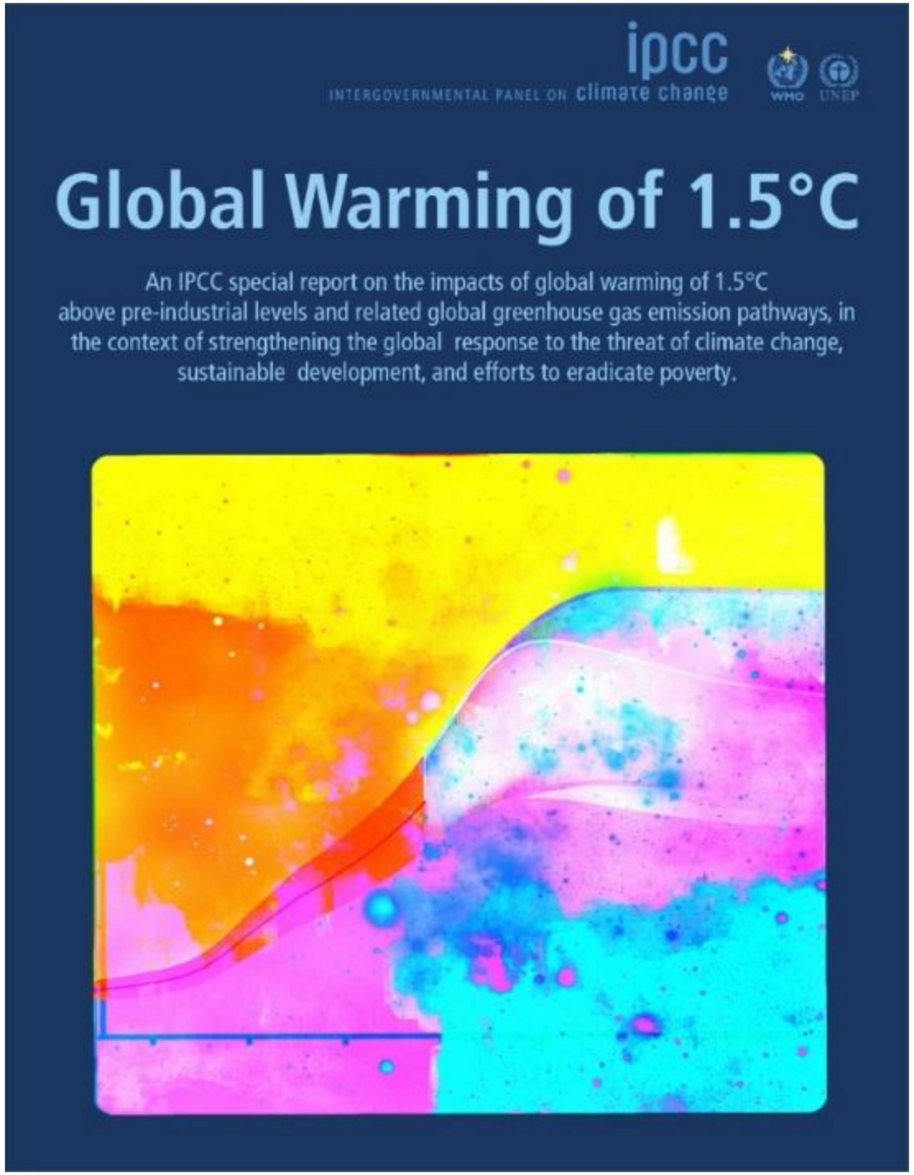
https://www.nature.com/articles/s41586-024-07602-x

Implications of 1.5°C, 2 °C or warmer by 2100



https://www.liveabout.com/global-warming-cartoons-4122873

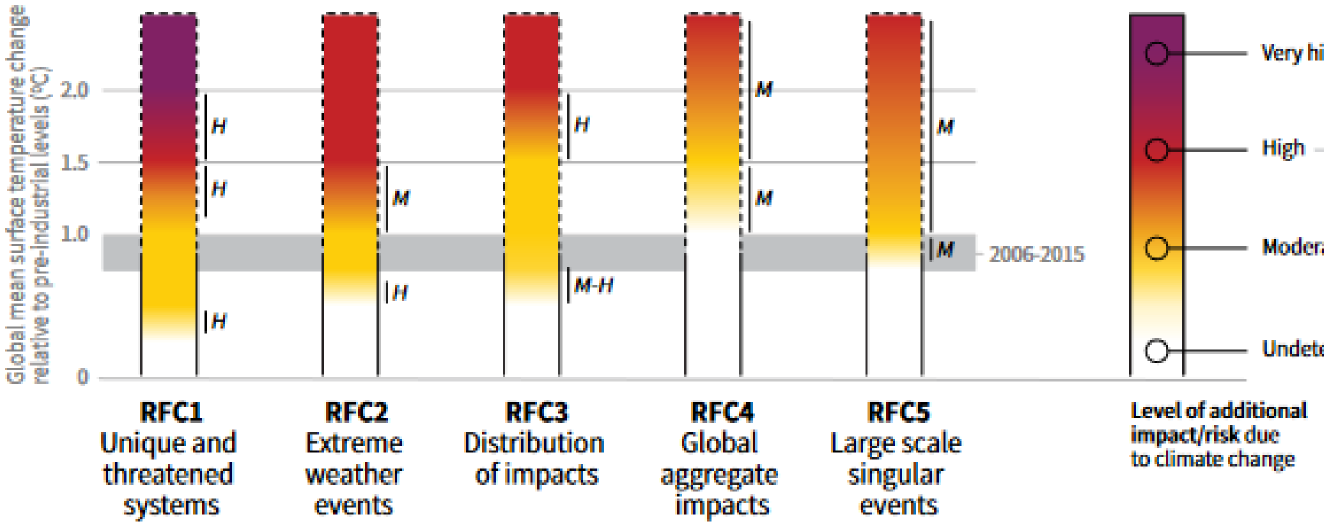
IPCC special report on 1.5° versus ≥ 2.0°C



Five Reasons For Concern (RFCs)

Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)

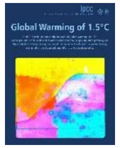


Purple indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
Red indicates severe and widespread impacts/risks.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

RFC4 Global aggregate impacts: global monetary damage, global-scale degradation and loss of ecosystems and biodiversity.

RFC5 relatively large, abrupt and sometimes irreversible changes in systems that are caused by global warming. Examples include disintegration of the Greenland and Antarctic ice sheets.

RFC1 ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its indigenous people, mountain glaciers and biodiversity hotspots.
RFC2 risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heat waves, heavy rain, drought and associated wildfires, and coastal flooding.
RFC3 risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability.



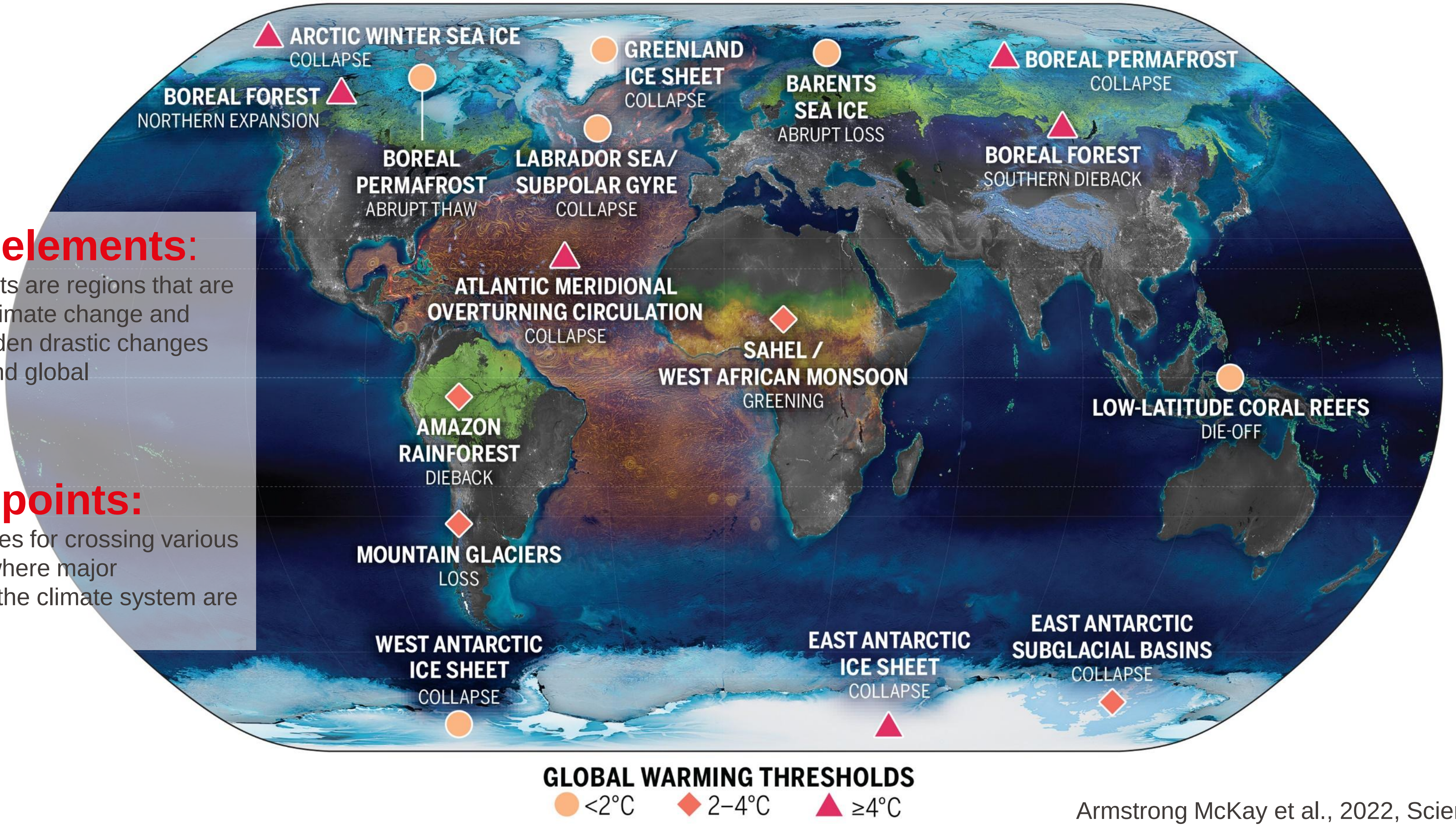
1.5°C versus warmer

- Limitation of global warming to 1.5°C compared to more than 2°C allows to avoid substantial additional changes in living conditions, in extremes and (irreversible) impacts.
- Living conditions
  - Sea level rise requires evacuation of neighborhoods / entire islands
  - Crops might not grow anymore where they used to, or new crops can be planted
  - Some regions will get too hot to live
  - …
- Extremes
  - Increase in hot extremes in most inhabited regions of the world
  - Heavier precipitation accompanied by cyclones in several regions
  - Increased droughts in some regions
  - …
- Irreversible impacts
  - Sea level rise,
  - Loss of glaciers and sea ice
  - Biodiversity loss: e.g., extinction of animals, plants, corals
  - …

Tipping points: What is at stake?

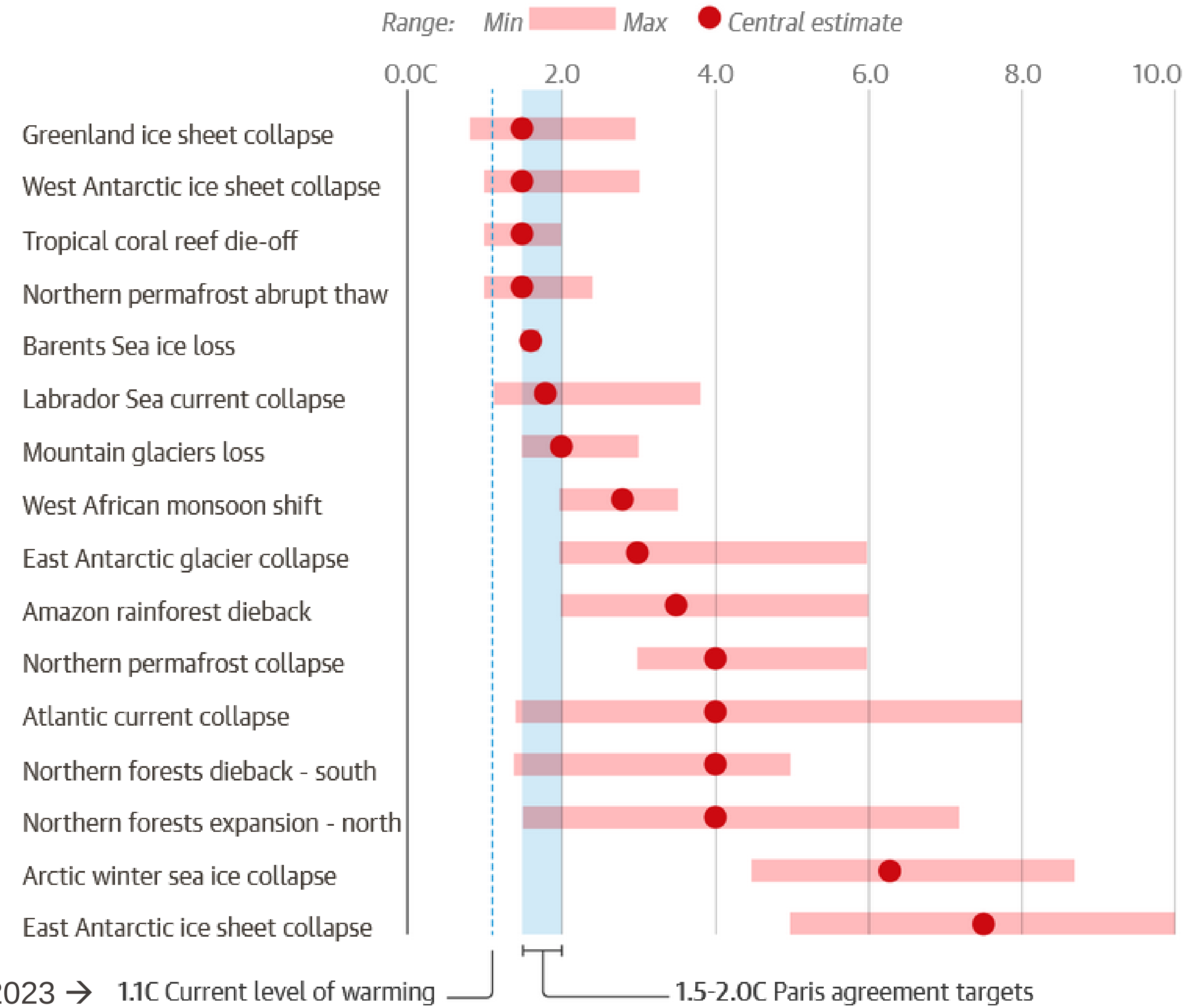
Tipping elements:
Tipping elements are regions that are vulnerable to climate change and capable of sudden drastic changes with regional and global consequences.

Tipping points:
Threshold ranges for crossing various tipping points where major subsystems of the climate system are destabilized.



Armstrong McKay et al., 2022, Science

What can the Paris Agreement prevent?



1.2 °C in 2023 →

Guardian graphic. Source: Armstrong McKay et al, Science, 2022. Note: Current global heating temperature rise 1.1C Paris agreement targets 1.5-2.0C

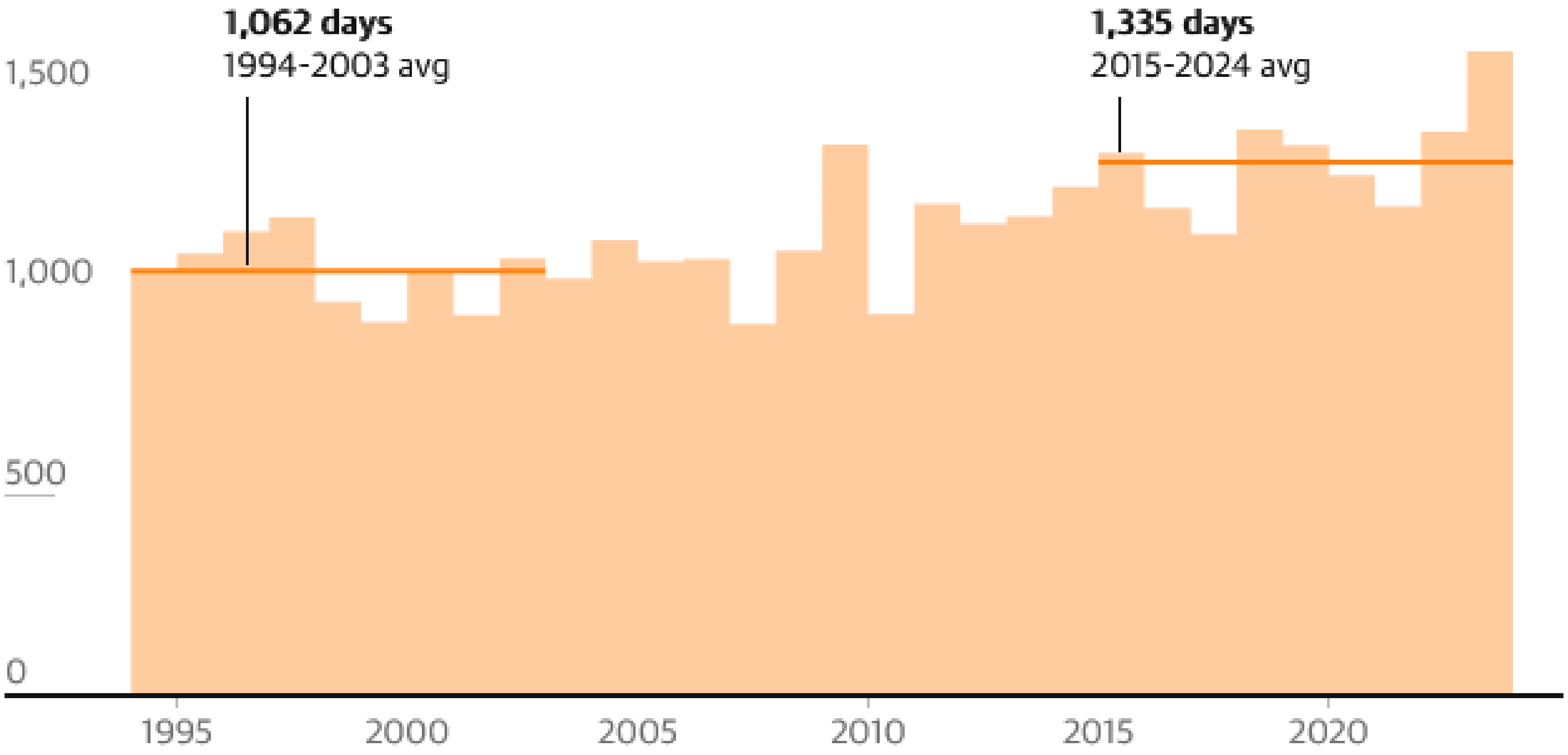
Reading Task

- **World's major cities hit by 25% leap in extremely hot days since the 1990s**
- https://www.theguardian.com/environment/2025/sep/30/worlds-major-cities-hit-by-25-leap-in-extremely-hot-days-since-the-1990s

- Focus on:
  - **What has been calculated?**
  - **What's the main finding and why is it important?**
  - **Why 35°C?**

Days of extreme heat in the world's biggest capital cities have risen by a quarter since 1994

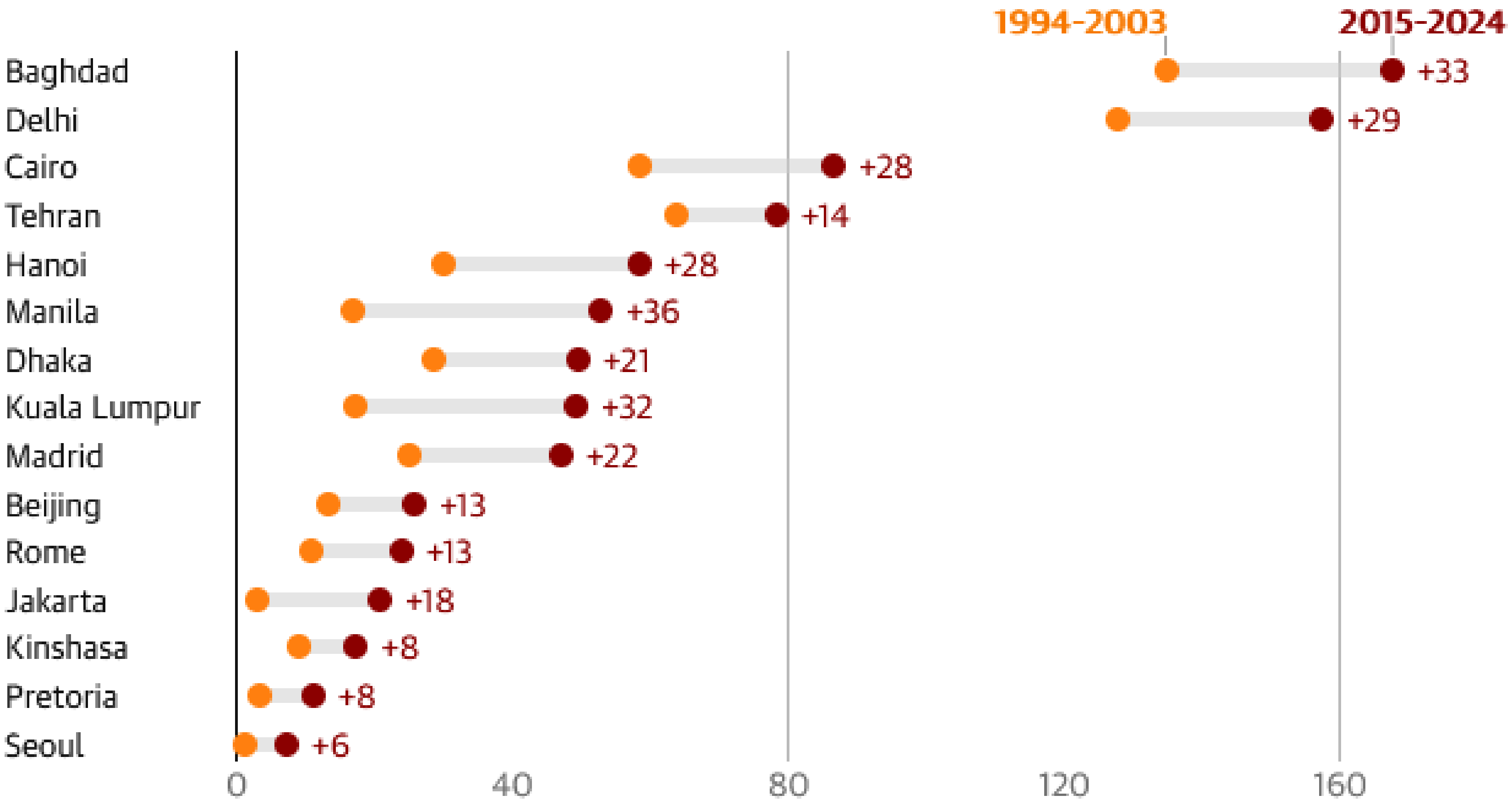
Days over 35C in a year in 43 cities*



Guardian graphic. Source: International Institute for Environment and Development. *40 most populous capital cities plus three cities with political significance. Khartoum and Abuja replaced by Kampala and Berlin due to a lack of data

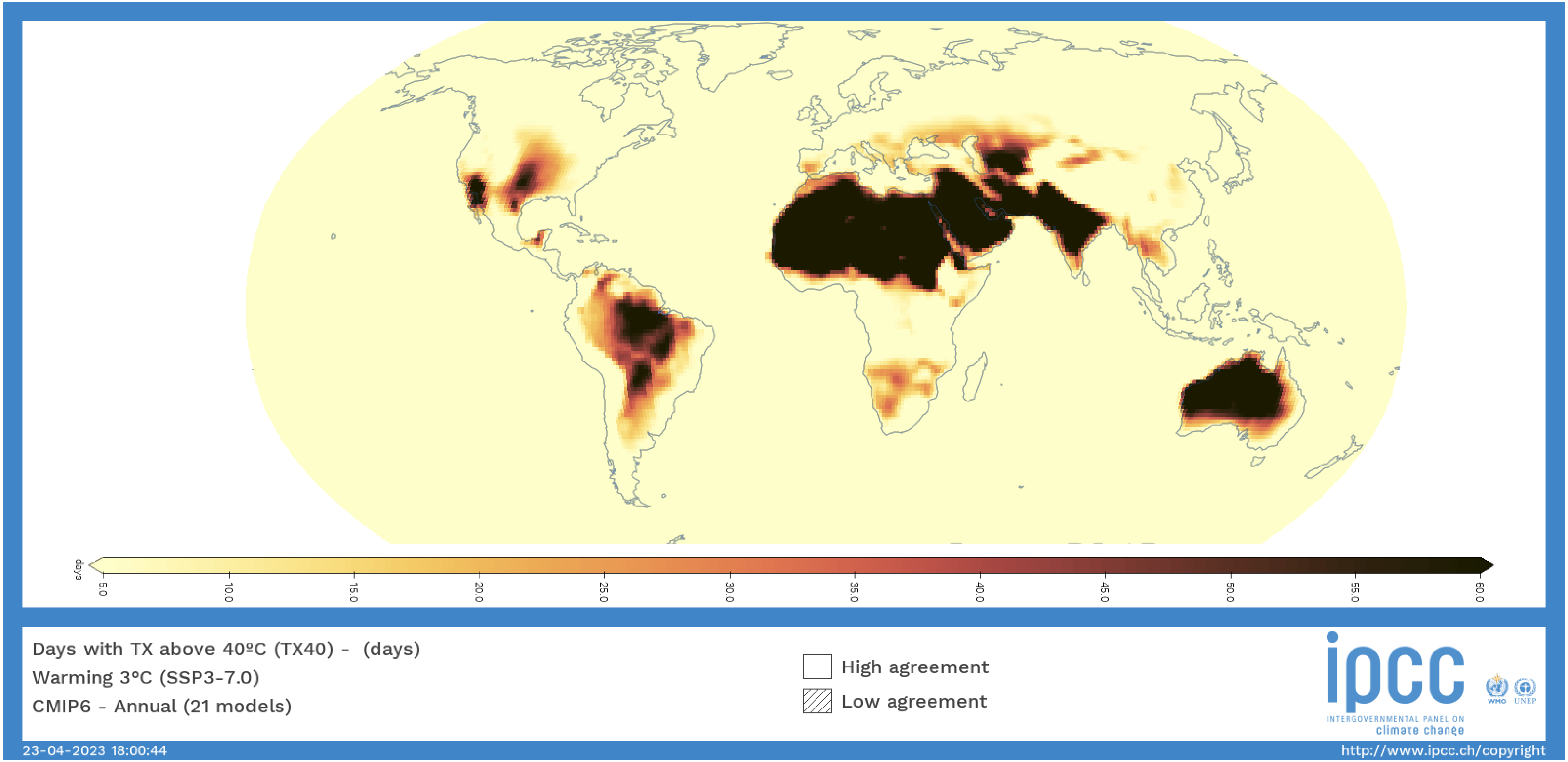
On average, Baghdad now experiences extreme heat for an additional 33 days of the year

Cities with the largest increase in the average number of days over 35C



Guardian graphic. Source: International Institute for Environment and Development. Notes: 40 most populous capital cities plus 3 cities with political significance.

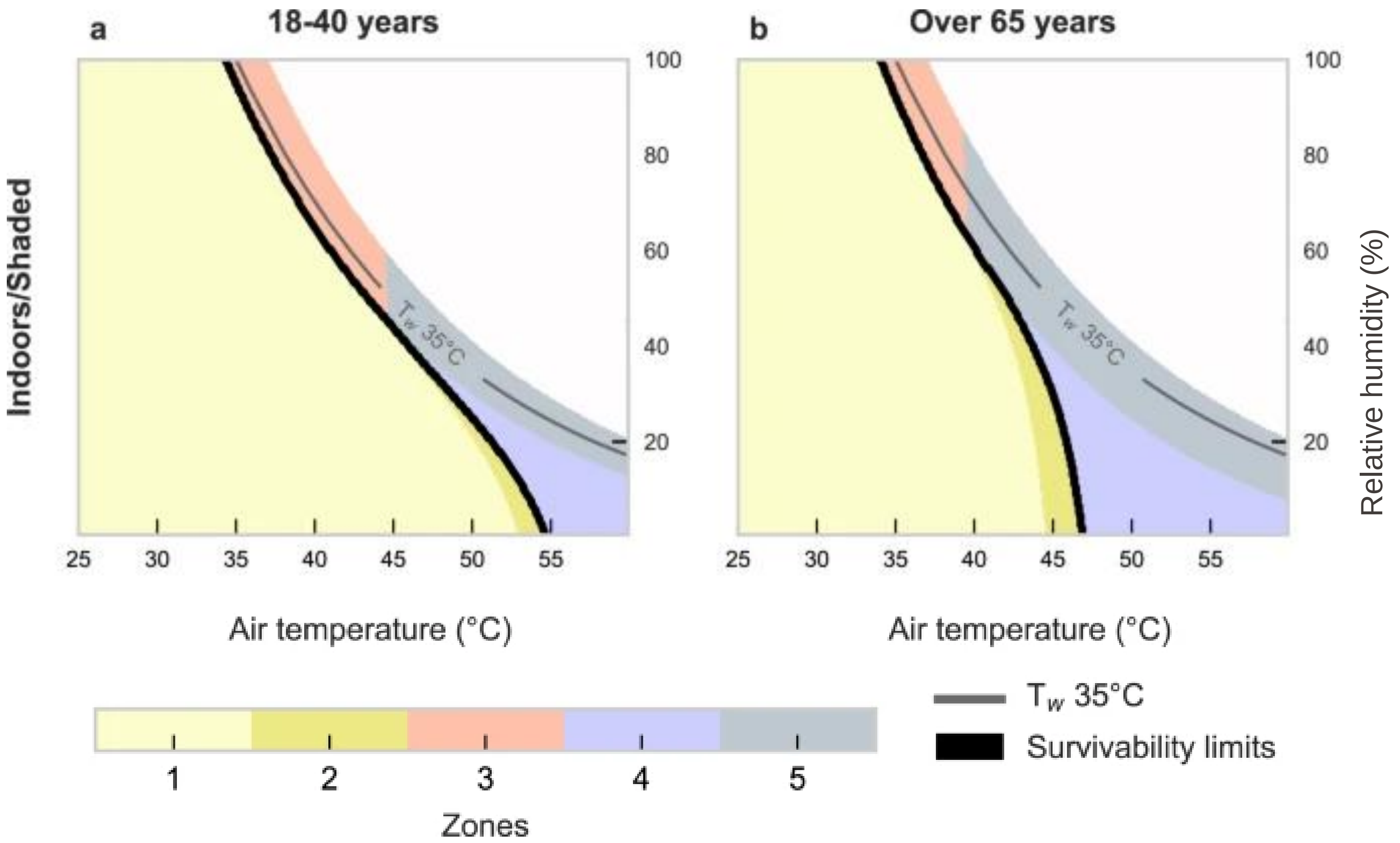
Days > 40°C @ 3°C warming



Implications of a hot climate

A **wet-bulb temperature (T_w) of 35°C** has been proposed as the theoretical physiological limit for human adaptability. This threshold was based on the fact that there would be no evaporative cooling possible from fully wetted skin which has a temperature of 35°C at T_w = 35°C.

Wet-bulb temperature is the lowest temperature to which air can be cooled by the evaporation of water into the air. **At 100% relative humidity, the wet-bulb temperature is equal to the air temperature** (dry-bulb temperature); at lower humidity the wet-bulb temperature is lower than dry-bulb temperature because of evaporative cooling.

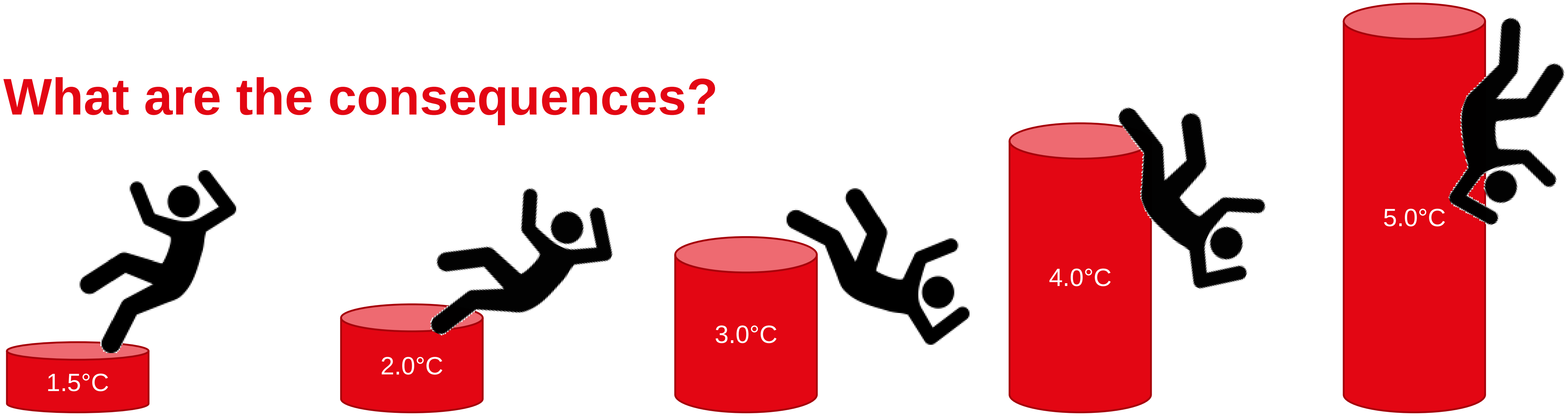


If the wet-bulb temperature is too high in certain regions on Earth, these areas become uninhabitable. Some parts of the population are affected more than others.

- https://www.nature.com/articles/s41467-023-43121-5

1.5°C versus warmer

What are the consequences?



EPFL

Extreme Events

Types of extreme events

- Heatwaves
- Droughts
- Crop failure
- Wildfires
- Floods
- Tropical Cyclones

- https://climatescenarios.org/extreme-events/

What is an extreme climate/weather event?

- **Extreme event:**
  The occurrence of a value of a weather variable above (or below) a threshold value near the upper (or lower) end of the range of its observed values in a specific region.

- **Return period:**
  An estimate of the average time interval between occurrences of an event (e.g., flood or extreme rainfall) of a defined size or intensity.

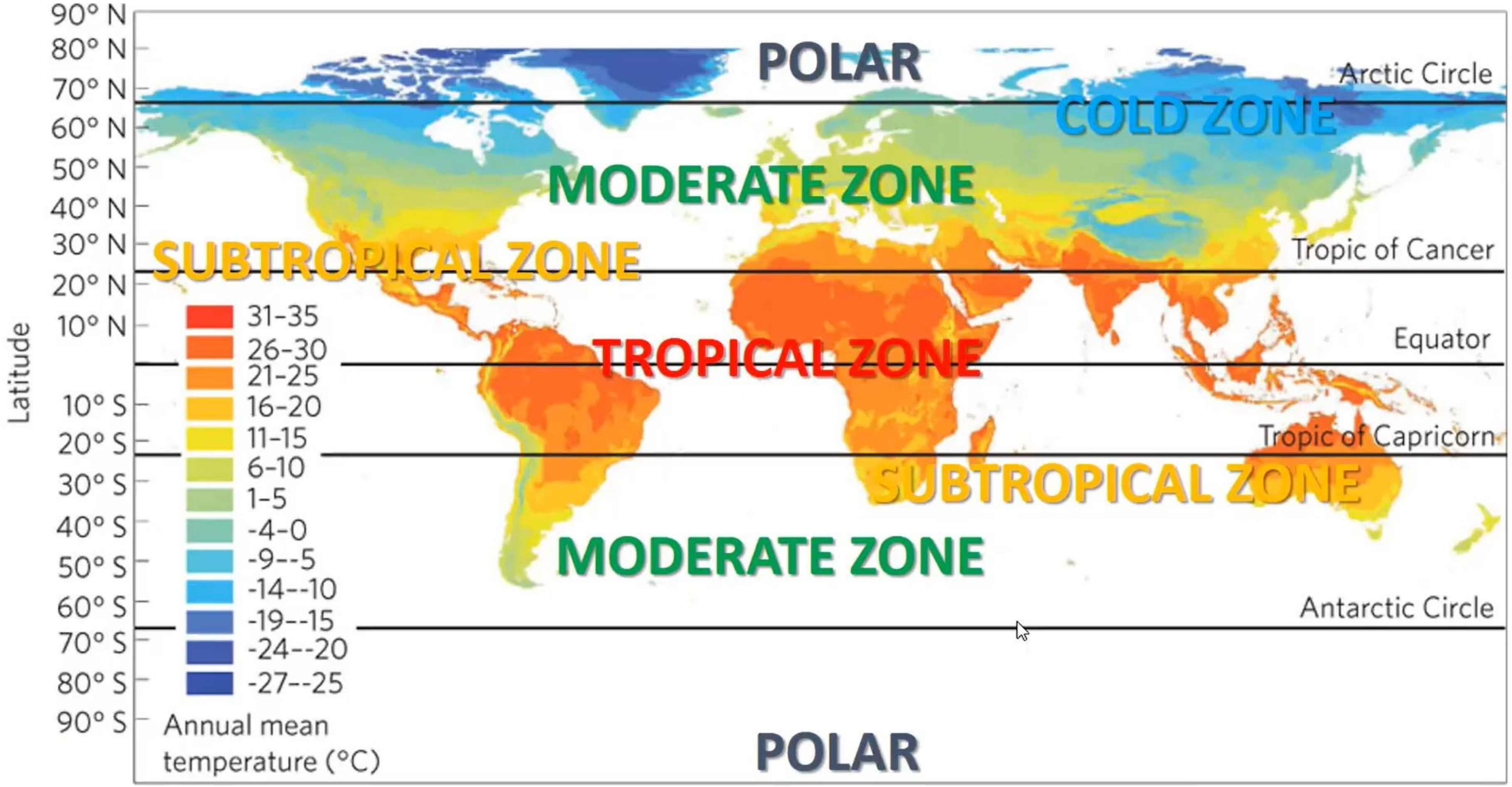
What is an extreme climate/weather event?

- Language used in climate science is not always very precise
  - Exceedance over a relatively low threshold
    - E.g., 10th, 90th percentile of daily temperature or rainfall
  - Rare events (long return period)
  - Unprecedented events (in the available record)

- Range from very small scale (tornados, hail storms) to large sale (drought, heat wave)

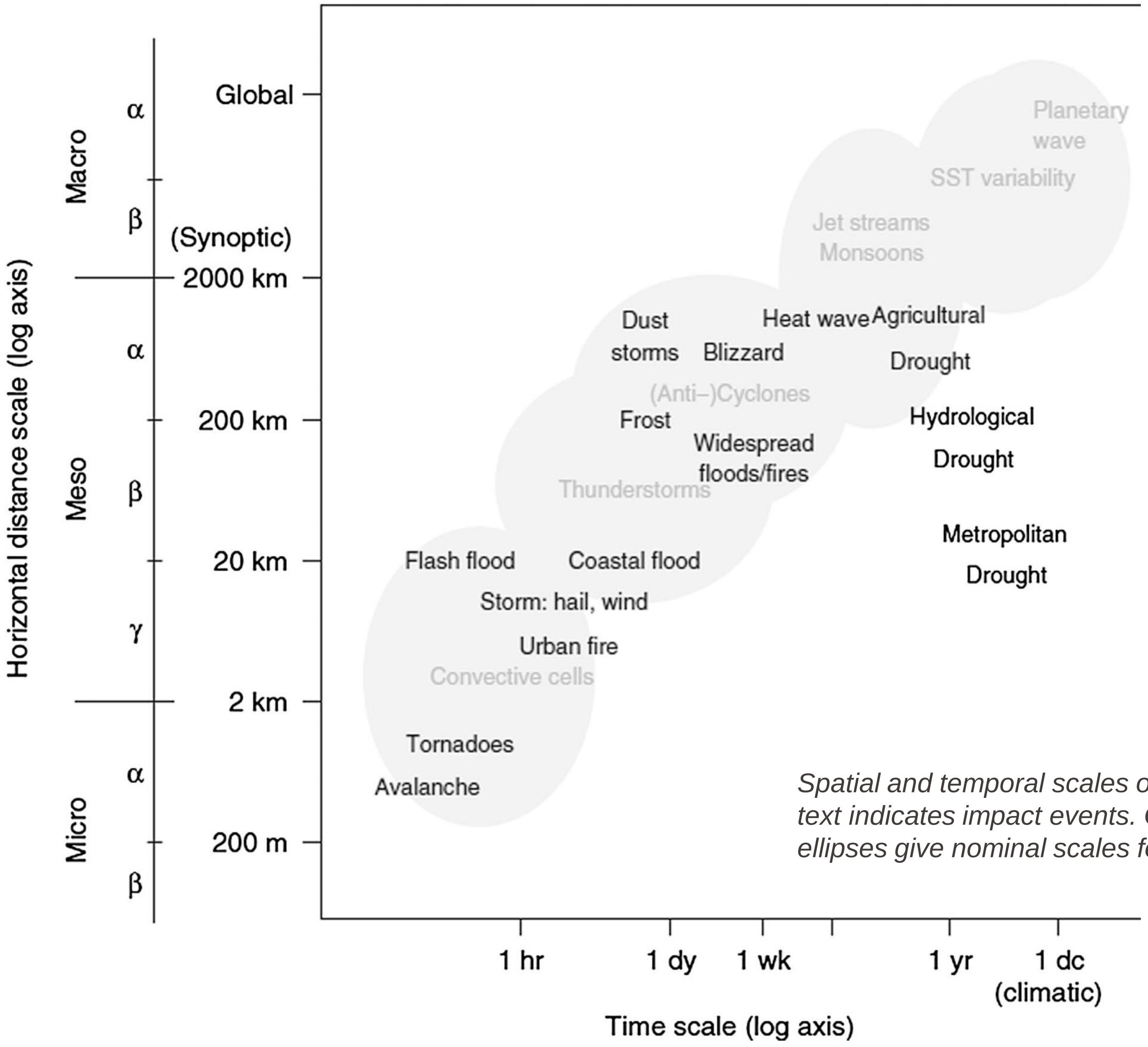
- Extremes in one location may be normal in another.

Climate zones – it's all relative



Saikkonen et al. NCC, 2012

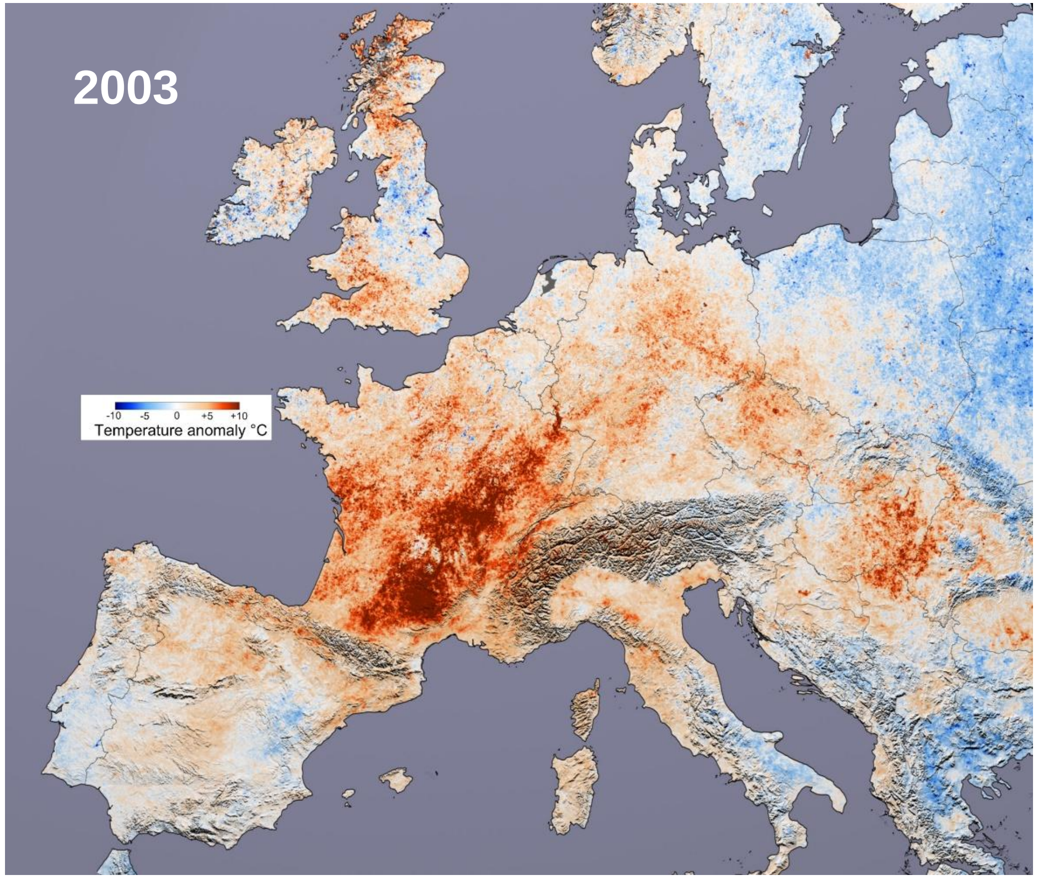
Spatial and temporal scales



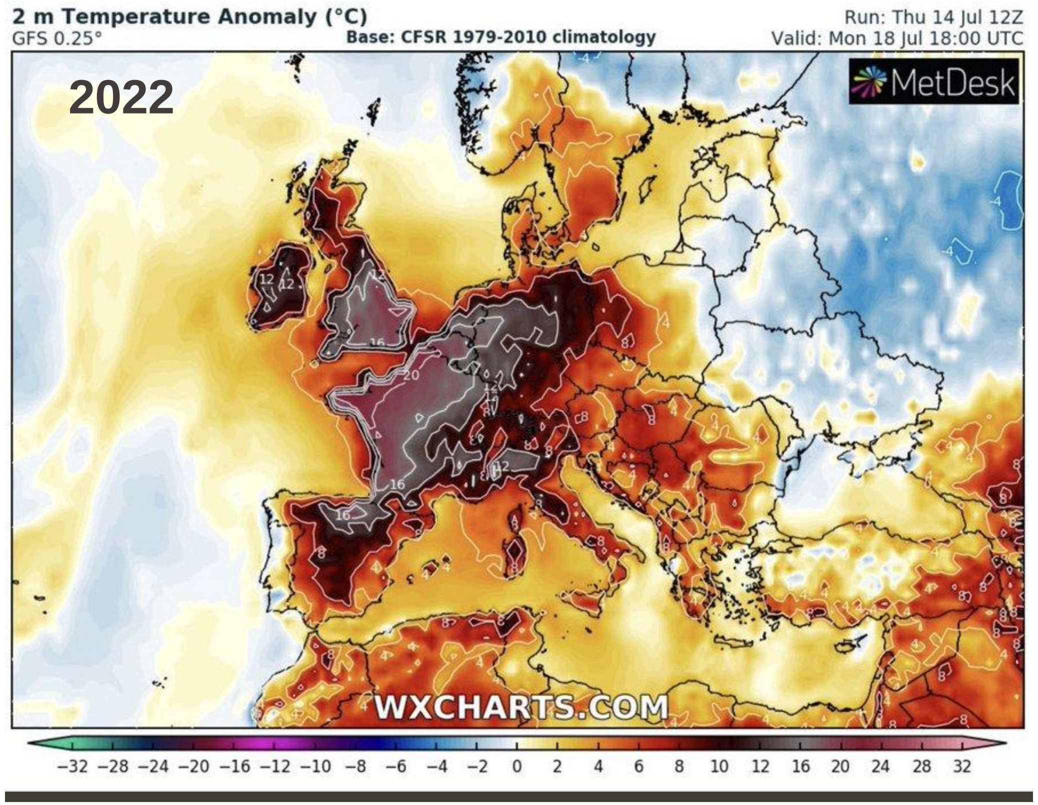
Spatial and temporal scales of typical events. Black text indicates impact events. Grey text and shaded ellipses give nominal scales for climatic events.

Leonard et al. (2014), https://wires.onlinelibrary.wiley.com/doi/10.1002/wcc.252

Spatial extent



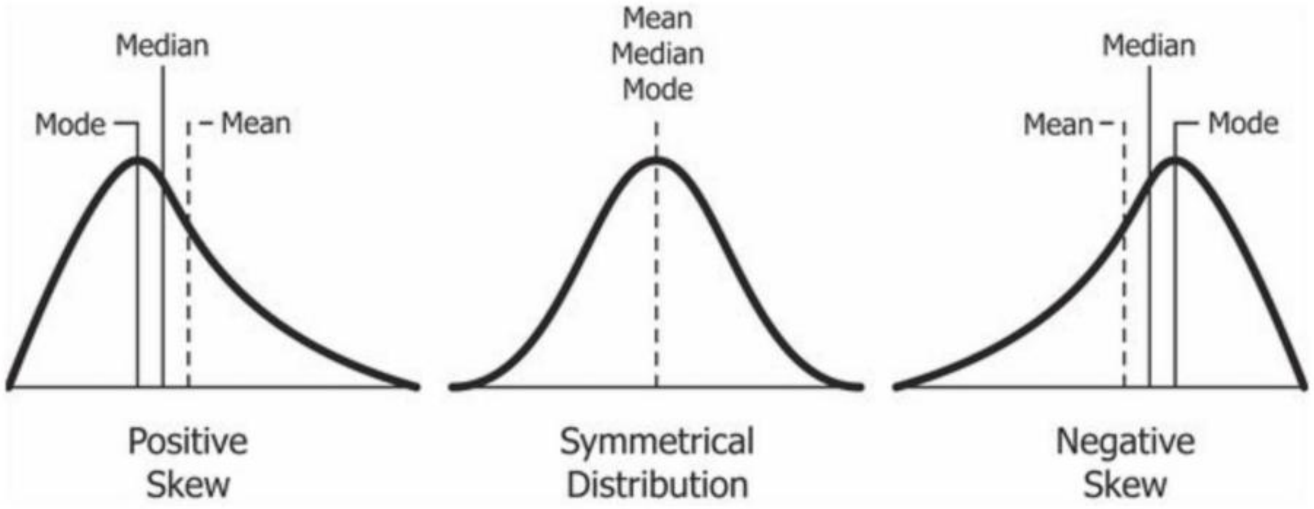
https://en.wikipedia.org/wiki/2003_European_heat_wave#/media/File:Canicule_Europe_2003.jpg



https://www.fastcompany.com/90770137/heatwave-europe-maps-show-historic-hot-weather-in-uk-france-and-across-the-continent

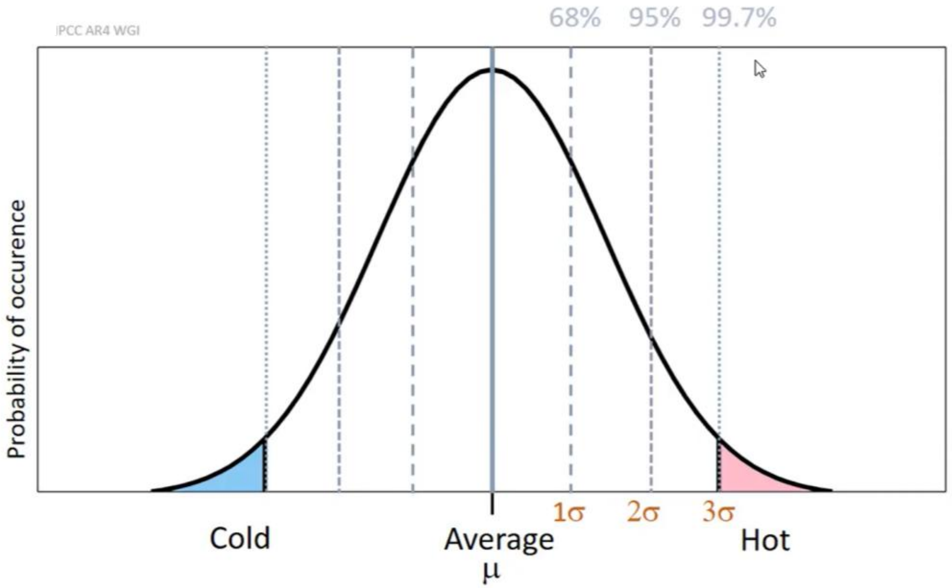
Climate value distributions

Precipitation **Temperature**

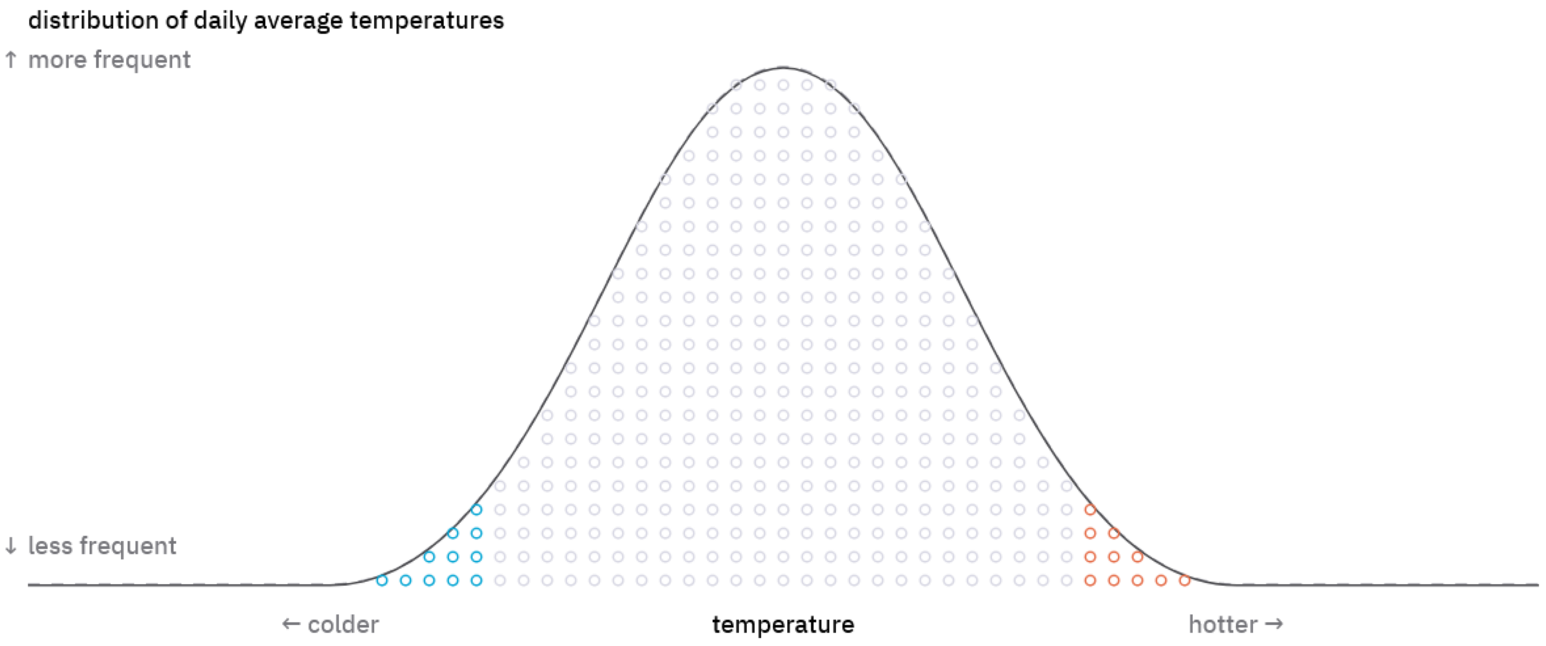


Wikipedia

Probabilit Density Function (PDF) of daily temperatures in a specific location and time.



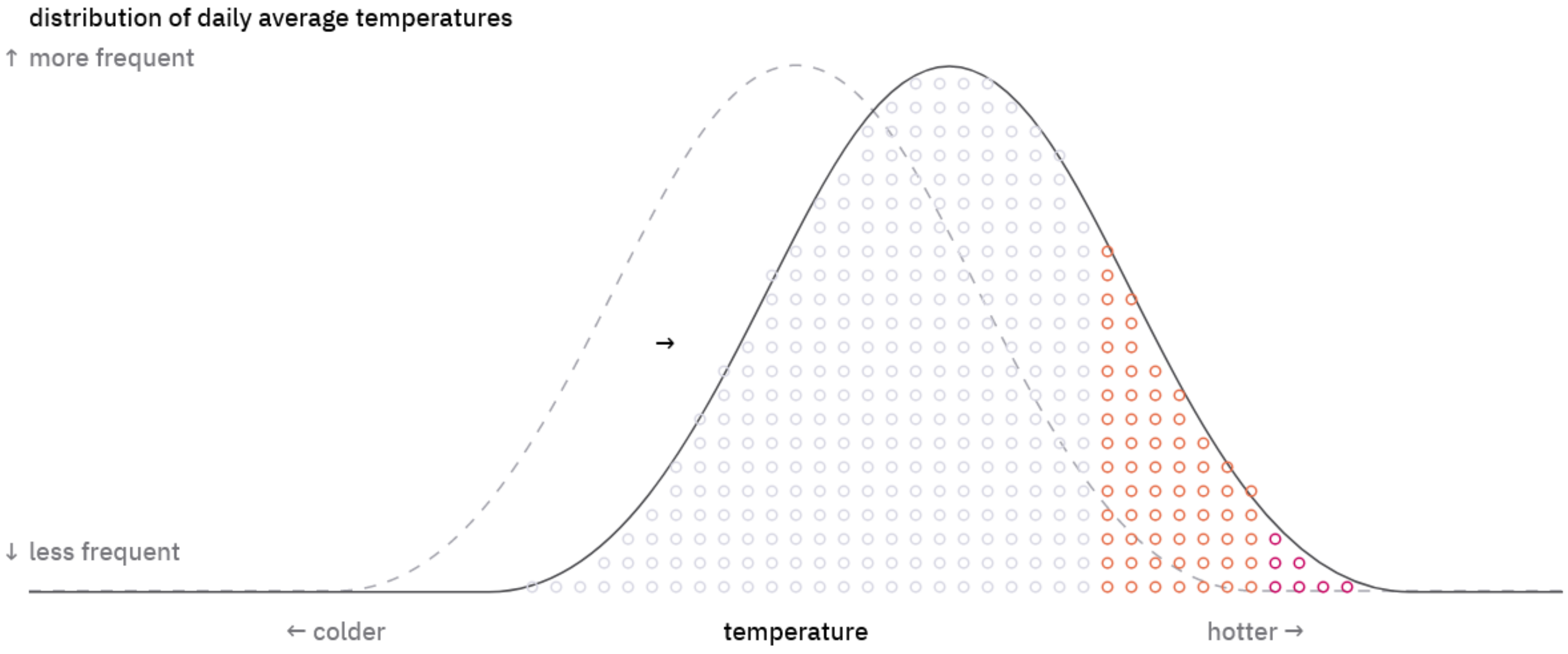
Climate extremes in a changing climate: «old climate»



This results in a normal distribution with most days having fairly average temperatures. Extreme events, here particularly cold or hot days lie in the tails of the distribution. They are quite rare.

- https://climatescenarios.org/extreme-events/

Climate extremes in a changing climate: new climate

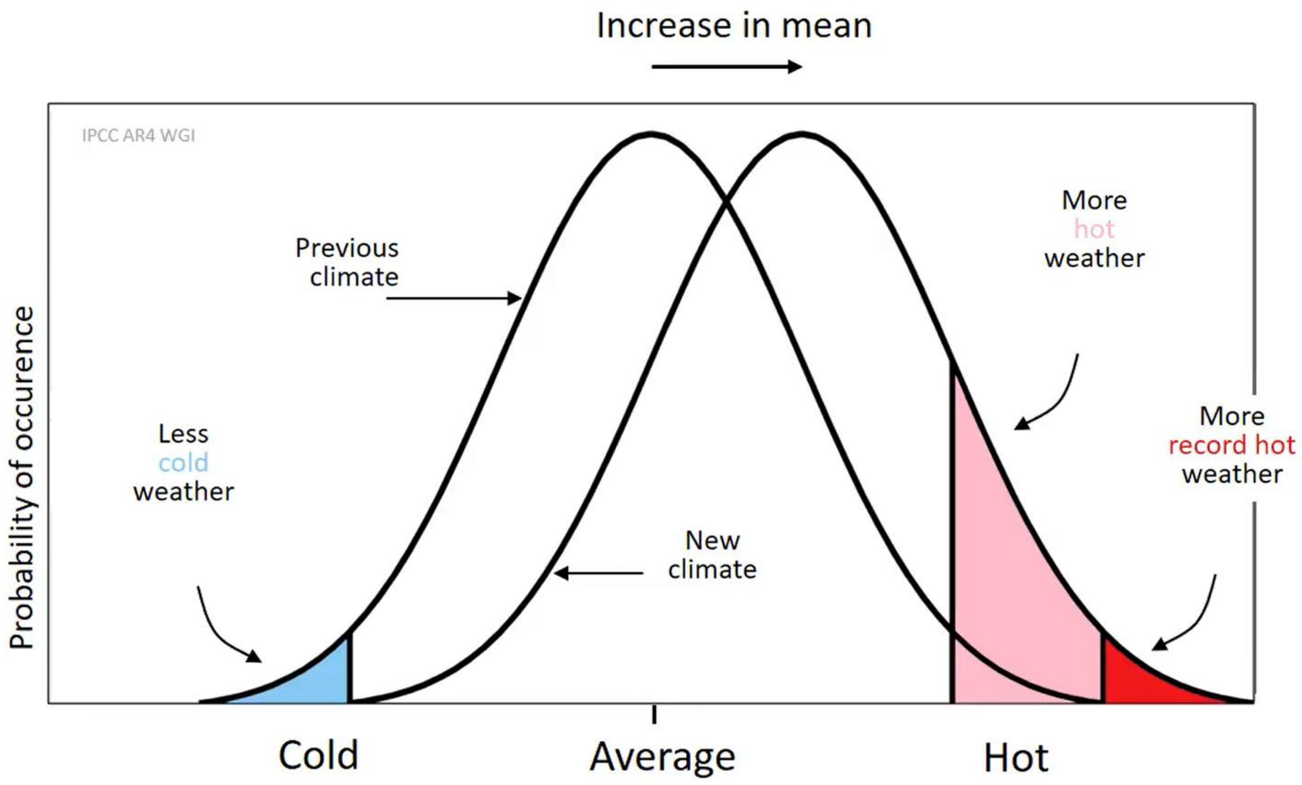


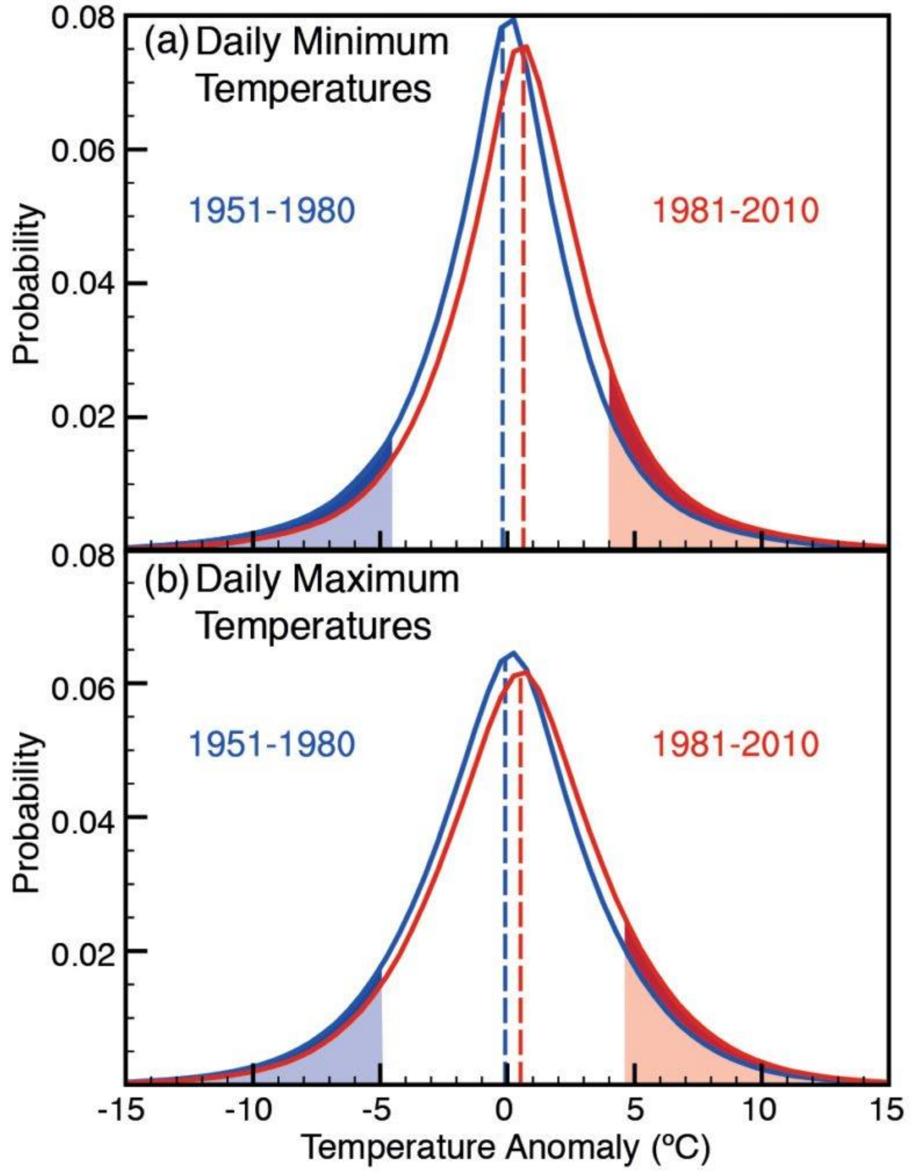
Under climate change, the mean temperature rises, and the distribution shifts to higher temperatures. Hot days that have been rare in the past occur now more frequently and reach even higher temperatures.

- https://climatescenarios.org/extreme-events/

Climate extremes in a changing climate

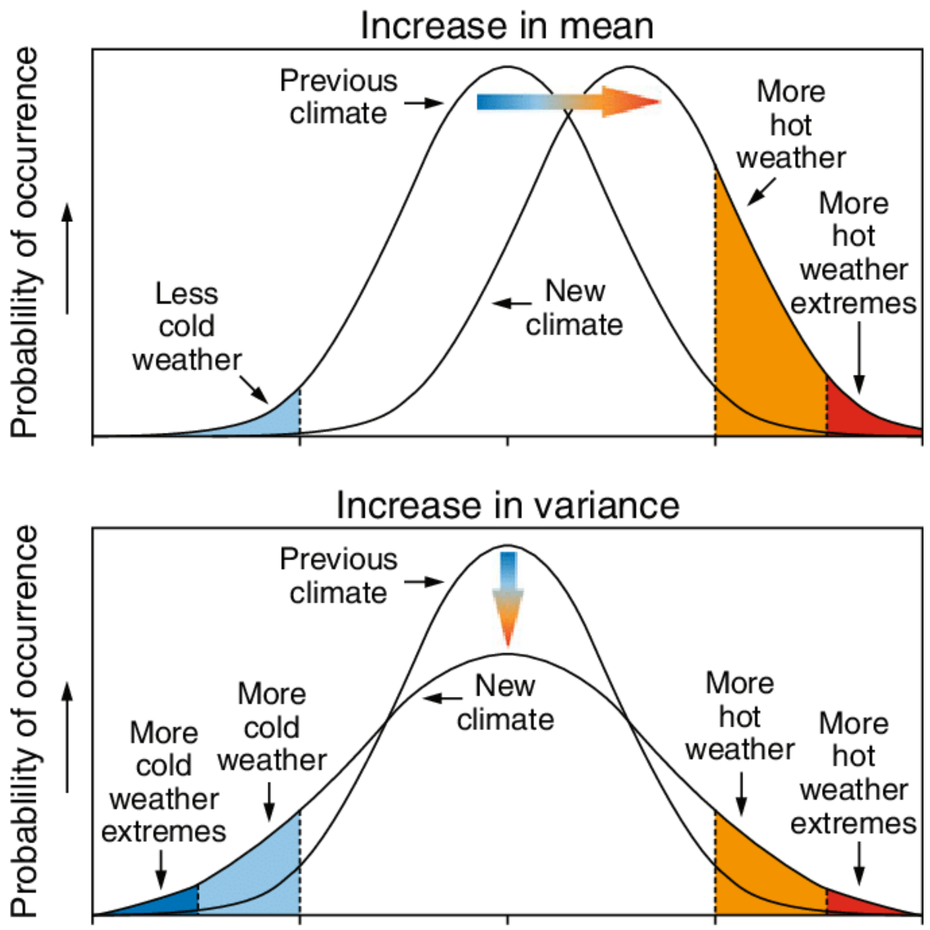
IPCC AR5 FAQ2.2

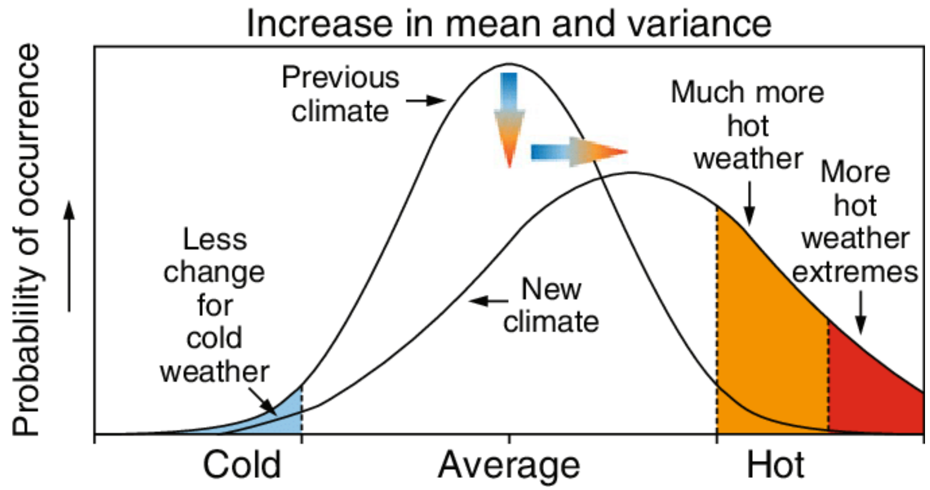


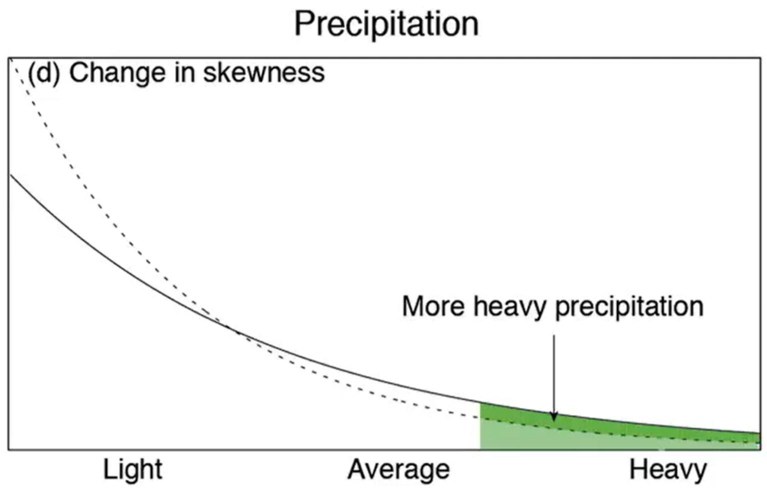


FAQ 2.2, Figure 1 | Distribution of (a) daily minimum and (b) daily maximum temperature anomalies relative to a 1961–1990 climatology for two periods: 1951–1980 (blue) and 1981–2010 (red) using the HadGHCND data set. The shaded blue and red areas represent the coldest 10% and warmest 10% respectively of (a) nights and (b) days during the 1951–1980 period. The darker shading indicates by how much the number of the coldest days and nights has reduced (dark blue) and by how much the number of the warmest days and nights has increased (dark red) during the 1981–2010 period compared to the 1951–1980 period.

Climate extremes in a changing climate





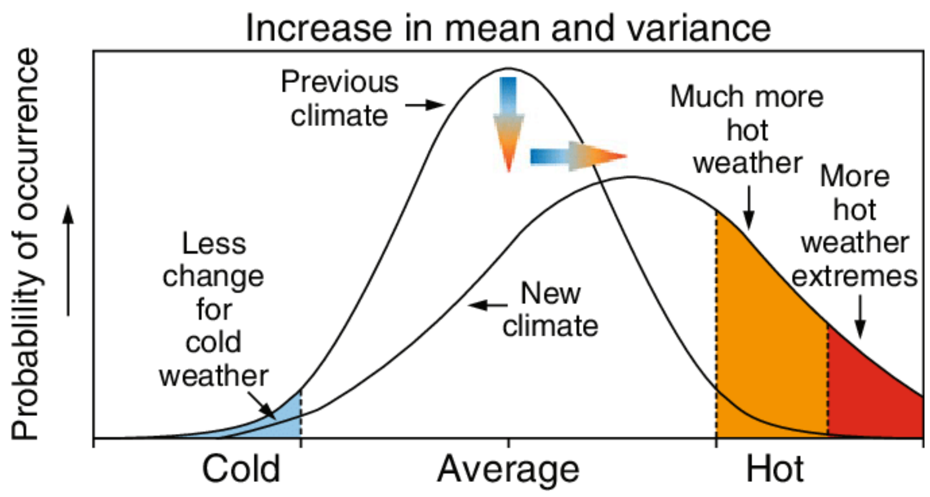


Distribution has a different shape for precipitiation. More skewed.

- IPCC AR3 Ch2.7

Challenges defining extreme events

- Extreme events are rare in time and space → there is a lack of observational data.
- Non-stationary climate.
- No universally valid definition.
  - Dependency on scale, location, time, and context

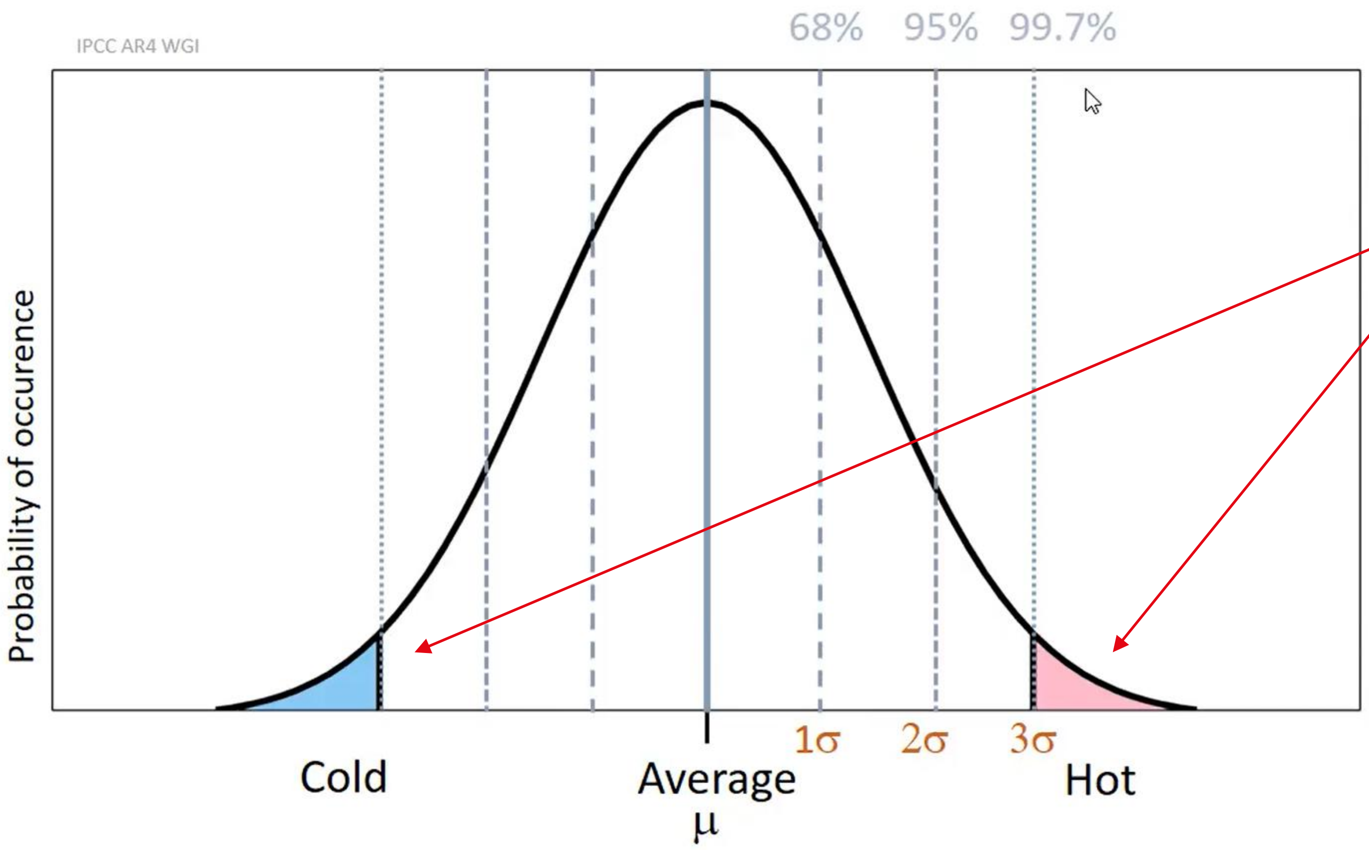


Finding a general definition

- **Extreme Value Distributions**
  - Continuous probability distributions developed within extreme value theory
  - Calculation of return values

- **Metrics for absolute count or threshold exceedance (indicators)**

Extreme value distributions



Normal distribution of temperature
For extreme value distribution, we only look at the tales (hot extremes or cold extremes).

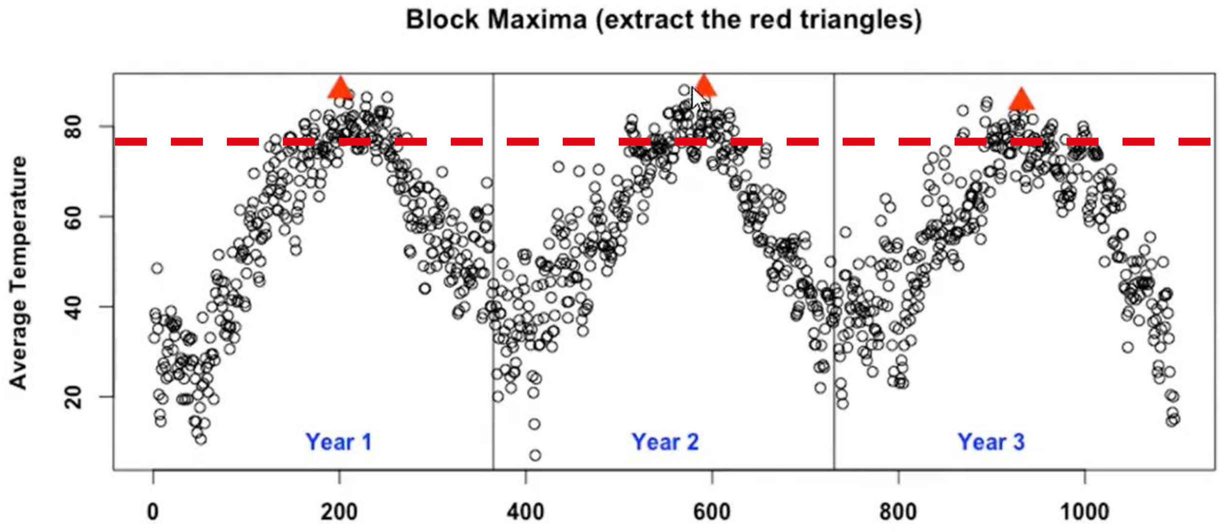
Fitting an extreme value distribution to climate data

$$M_n = max \{X_1, \ldots, X_n\}$$

where $\{X_1, \ldots, X_n\}$ is a sequence of independent random variables
M_n is the maximum of observed process over n time units, for n → ∞

Approaches to select maxima

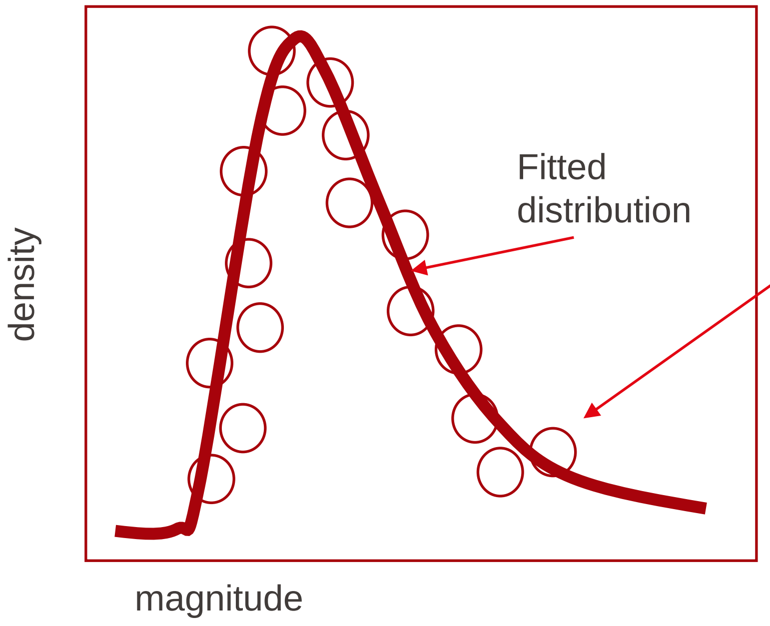
1. **Block maxima (maybe too little data)**
2. **Beyond a threshold (perhaps too many data to fit extreme value distribution)**

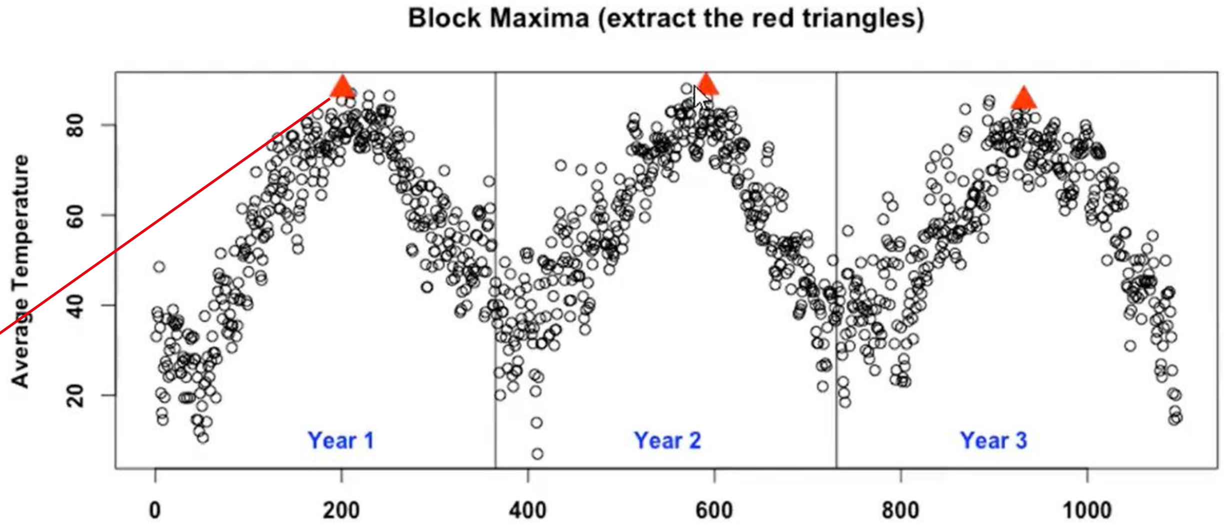


Adapted from and courtesy of J. Sillmann
http://www.dataanalysisclassroom.com/lesson60/

Fitting the extreme value distribution

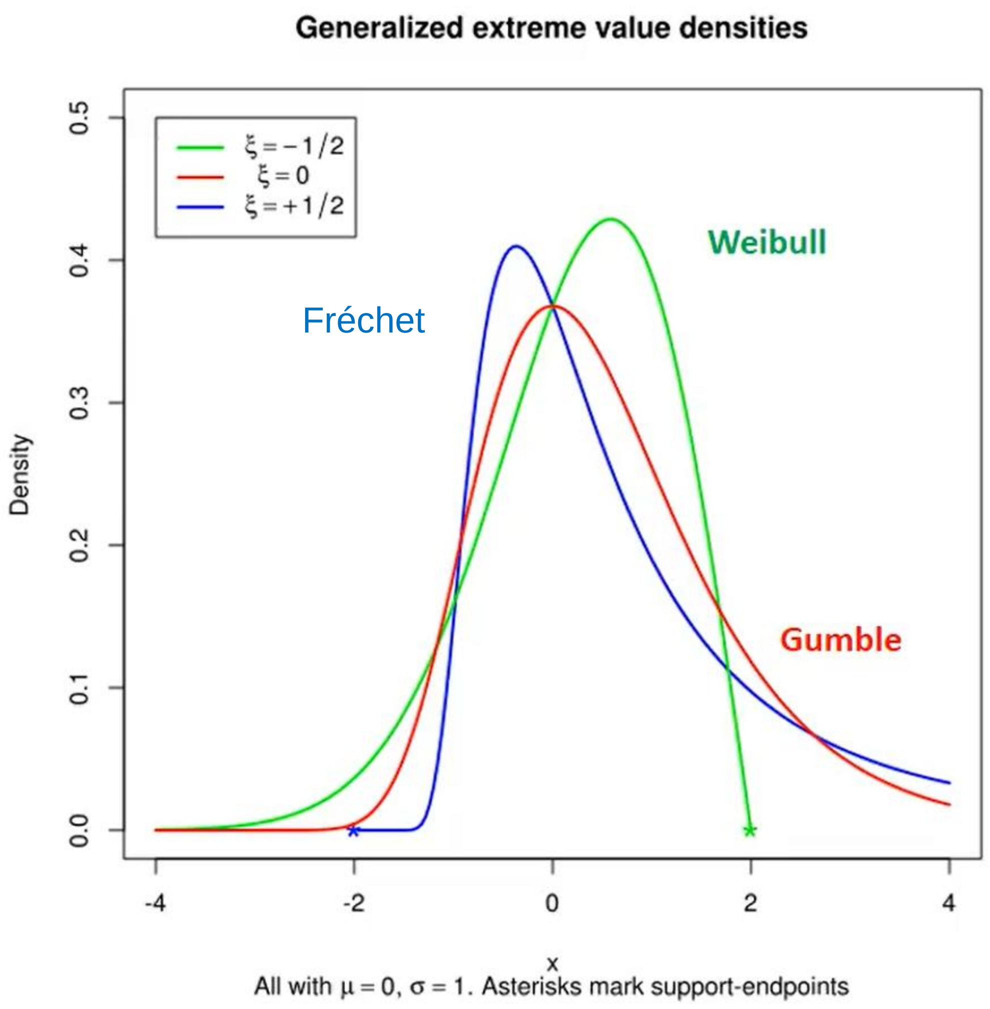
Generalized extreme value distribution





Data points from block maxima, e.g. from over 50 years.

General Extreme Value (GEV) distributions



The statistical distribution of the largest values drawn from a sample of a given size has only three possible shapes:

- Gumble, Fréchet, Weibull extreme value distributions

GEV aims to answer questions like:

- "If I divide up this hundred-hour interval into a hundred 1-h intervals, what would be the statistical distribution of strongest signal in each 1-h interval?"
- "If the strongest signal I have observed over the last hour had the value *x*, what would the strongest signal expected to be if measured over hundred hours?" → what about the future?

μ = location (shift of distribution)
ζ = shape
σ = scale (width or spread of distribution)

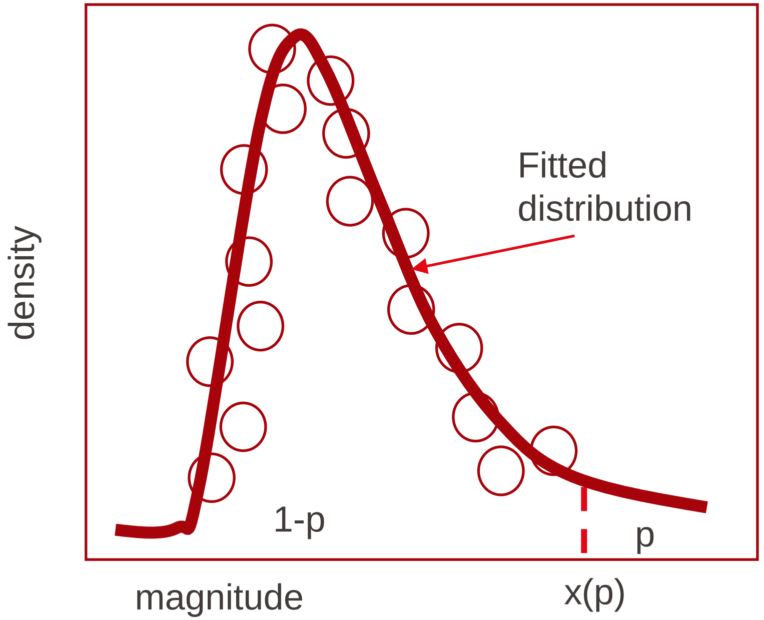
- https://www.frontiersin.org/articles/10.3389/fphy.2020.604053/full

Coles, Stuart (2001). An Introduction to Statistical Modeling of Extreme Values. Springer-Verlag. ISBN 1-85233-459-2.

Fitting the extreme value distribution and Extrapolation beyond the observed

How about the future? Values which we have not yet observed?

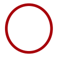
Generalized extreme value distribution



event x has probability p; x(p)

p = probability of exceedance
Return period **T = 1/p**

For example, if **p = 0.01**, then the return period is **T = 100 years**.

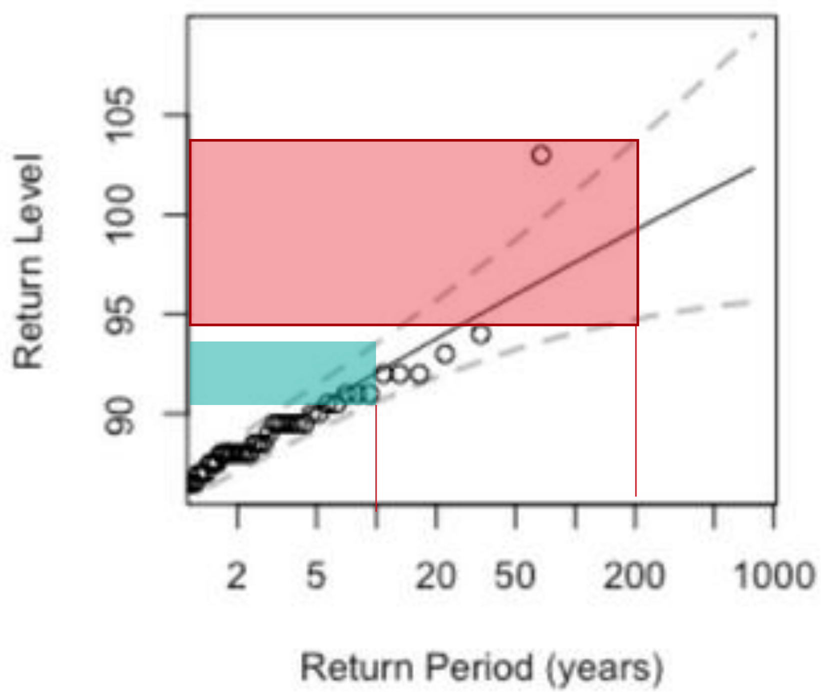

Data points from block maxima, e.g. From over 50 years.

Adapted from and courtesy of J. Sillmann

Return levels

How long do we have to wait until an event of the same magnitude arrives?

Temperature (°F)



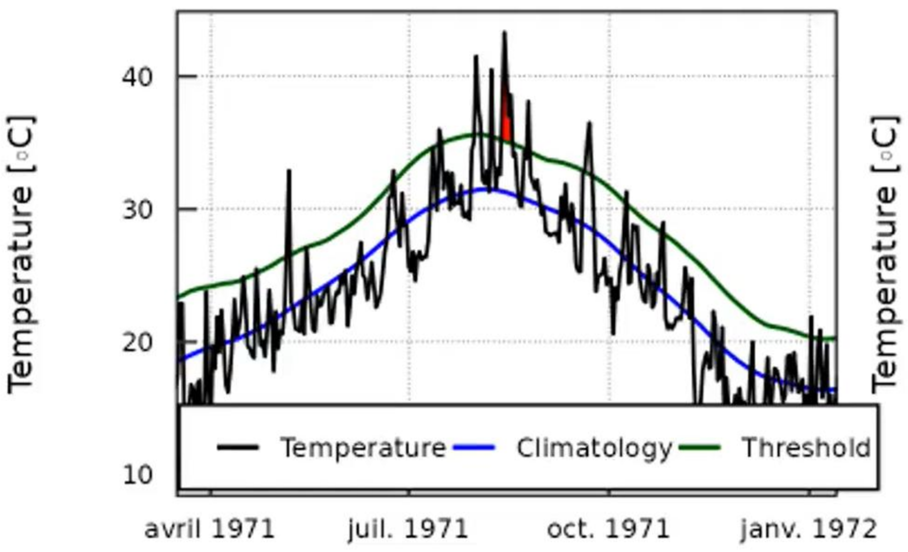
Uncertainty becomes larger for longer return periods
Also climate will change over longer time horizons (not stationary climate). This has to be taken into account.

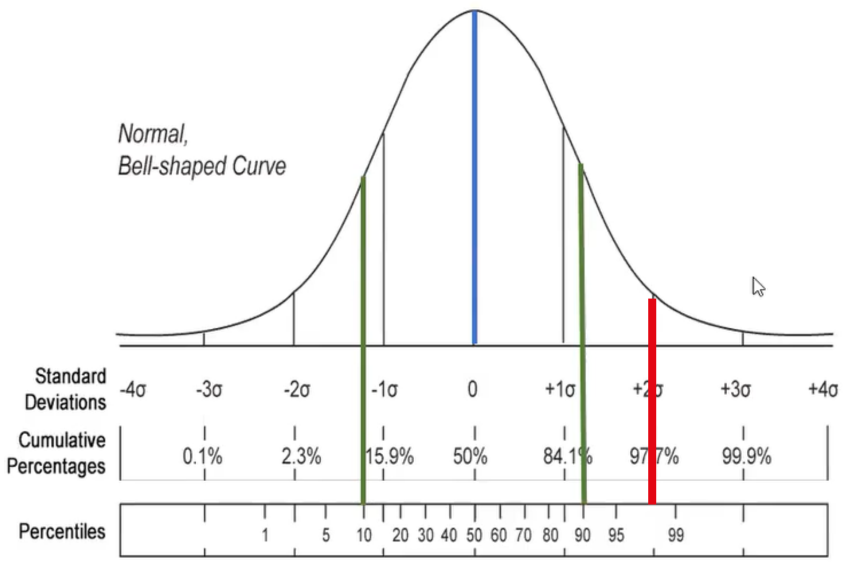
Finding a general definition

- Extreme Value Distributions
  - Continuous probability distributions developed within extreme value theory
  - Parametric
  - Calculation of return values

- **Metrics for absolute count or threshold exceedance (indicators)**

Percentile-threshold indices





EPFL

Indices for Climate Extremes

Annex VI — Climatic Impact-driver and Extreme Indices

Table AVI.1 | Table listing extreme indices used in Chapter 11.

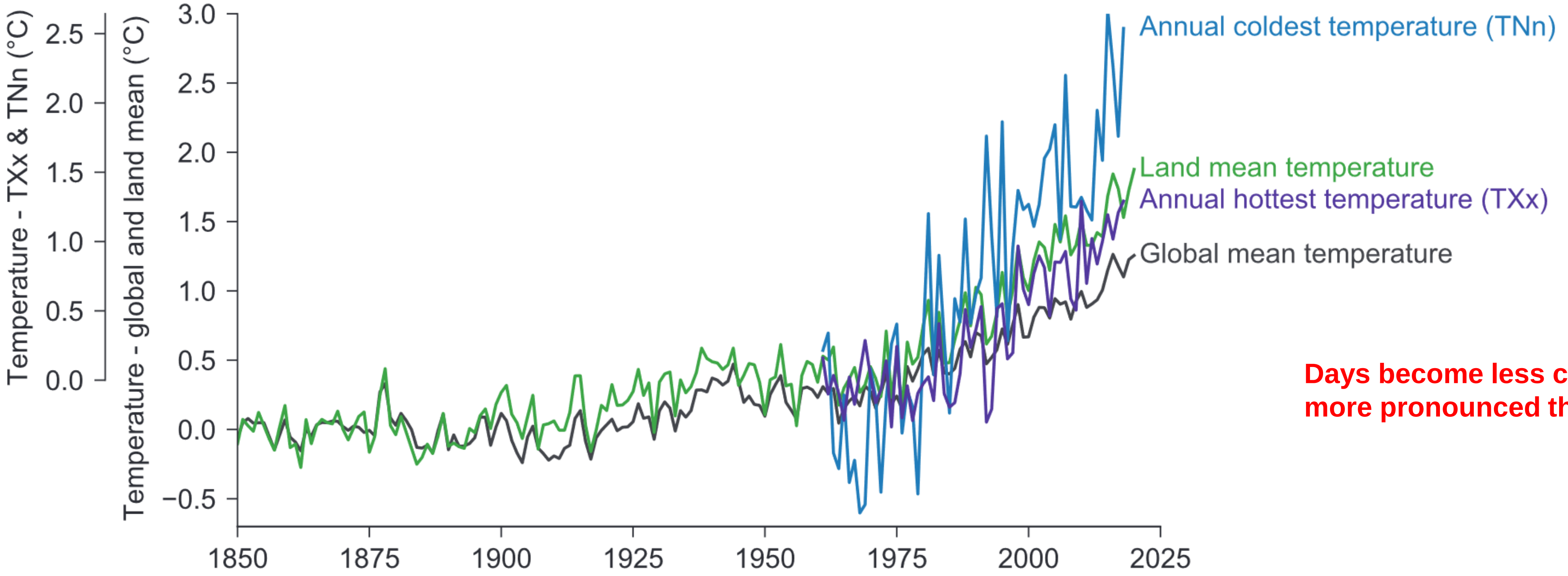
Extreme	Label	Index Name	Units	Variable
Temperature	TXx	Monthly maximum value of daily maximum temperature	°C	Maximum temperature
	TXn	Monthly minimum value of daily maximum temperature	°C	Maximum temperature
	TNn	Monthly minimum value of daily minimum temperature	°C	Minimum temperature
	TNx	Monthly maximum value of daily minimum temperature	°C	Minimum temperature
	TX90p	Percentage of days when daily maximum temperature is greater than the 90th percentile	%	Maximum temperature
	TX10p	Percentage of days when daily maximum temperature is less than the 10th percentile	%	Maximum temperature
	TN90p	Percentage of days when daily minimum temperature is greater than the 90th percentile	%	Minimum temperature
	TN10p	Percentage of days when daily minimum temperature is less than the 10th percentile	%	Minimum temperature
	ID	Number of icing days: annual count of days when TX (daily maximum temperature) <0°C	Days	Maximum temperature
	FD	Number of frost days: annual count of days when TN (daily minimum temperature) <0°C	Days	Minimum temperature
	WSDI	Warm spell duration index: annual count of days with at least six consecutive days when TX >90th percentile	Days	Maximum temperature
	CSDI	Cold spell duration index: annual count of days with at least six consecutive days when TN <10th percentile	Days	Minimum temperature
	SU	Number of summer days: annual count of days when TX (daily maximum temperature) >25°C	Days	Maximum temperature
	TR	Number of tropical nights: annual count of days when TN (daily minimum temperature) >20°C	Days	Minimum temperature
	DTR	Daily temperature range: monthly mean difference between TX and TN	°C	Maximum and minimum temperature
	GSL	Growing season length: annual (1 Jan to 31 Dec in Northern Hemisphere (NH), 1 July to 30 June in Southern Hemisphere (SH)) count between first span of at least six days with daily mean temperature TG >5°C and first span after July 1 (Jan 1 in SH) of six days with TG <5°C	Days	Mean temperature
	20TXx	One-in-20 year return value of monthly maximum value of daily maximum temperature	°C	Maximum temperature
	20TXn	One-in-20 year return value of monthly minimum value of daily maximum temperature	°C	Maximum temperature
	20TNn	One-in-20 year return value of monthly minimum value of daily minimum temperature	°C	Minimum temperature
	20TNx	One-in-20 year return value of monthly maximum value of daily minimum temperature	°C	Minimum temperature

https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_AnnexVI.pdf

Indices for Climate Extremes

Precipitation	Rx1day	Maximum one-day precipitation	mm	Precipitation
	Rx5day	Maximum five-day precipitation	mm	Precipitation
	R5mm	Annual count of days when precipitation is greater than or equal to 5 mm	Days	Precipitation
	R10mm	Annual count of days when precipitation is greater than or equal to 10 mm	Days	Precipitation
	R20mm	Annual count of days when precipitation is greater than or equal to 20 mm	Days	Precipitation
	R50mm	Annual count of days when precipitation is greater than or equal to 50 mm	Days	Precipitation
	CDD	Maximum number of consecutive days with less than 1 mm of precipitation per day	Days	Precipitation
	CWD	Maximum number of consecutive days with more than or equal to 1 mm of precipitation per day	Days	Precipitation
	R95p	Annual total precipitation when the daily precipitation exceeds the 95th percentile of the wet-day (>1 mm) precipitation	mm	Precipitation
	R99p	Annual precipitation amount when the daily precipitation exceeds the 99th percentile of the wet-day precipitation	mm	Precipitation
	SDII	Simple precipitation intensity index	mm day^{-1}	Precipitation
	20Rx1day	One-in-20 year return value of maximum one-day precipitation	mm day^{-1}	Precipitation
	20Rx5day	One-in-20 year return value of maximum five-day precipitation	mm day^{-1}	Precipitation
Drought	SPI	Standardized precipitation index	Months	Precipitation
	EDDI	Potential evaporation, evaporative demand drought index	Months	Evaporation
	SMA	Soil moisture anomalies	Months	Soil moisture
	SSMI	Standardized soil moisture index	Months	Soil moisture
	SRI	Standardized runoff index	Months	Streamflow
	SSI	Standardized streamflow index	Months	Streamflow
	PDSI	Palmer drought severity index	Months	Precipitation, evaporation
	SPEI	Standardized precipitation evapotranspiration index	Months	Precipitation, evaporation, temperature

Observed changes in temperature extremes



Days become less cold, more pronounced than more hot

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).

- AR6, Ch11

Changes in frequency of extreme temperature events

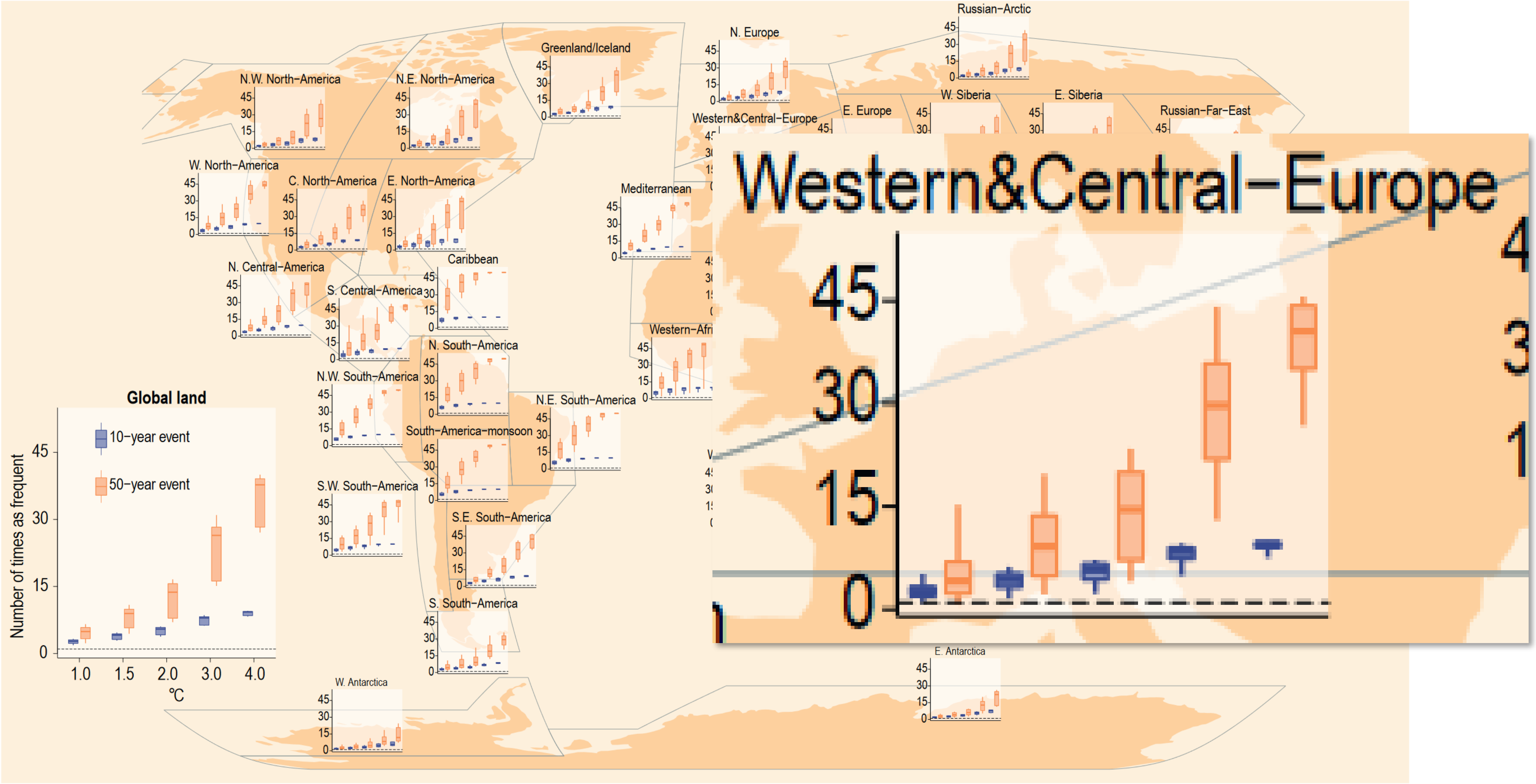


Figure 11.6 | Projected changes in the frequency of extreme temperature events under 1°C, 1.5°C, 2°C, 3°C, and 4°C global warming levels relative to the 1850–1900 baseline. Extreme temperatures are defined as the maximum daily temperatures that were exceeded on average once during a 10-year period (10-year 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).

IPCC AR6

Two sets of metrics for the frequency of hot/warm days have been used in the literature:

- One set **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.
  - An event based on such a definition can occur at any time of the year, and the impact of such an event would differ depending on the season.
- The other set **counts the number of days** in which maximum daily temperature is **above an absolute threshold** such as 35°C, because exceeding this temperature can sometimes cause health impacts
  - These impacts may depend on location and whether ecosystems and the population are adapted to such temperatures.

The resulting meaning of “extreme” is different.

- From AR6, Ch 11.2.1

Moving targets

- When similar damage occurs once a fixed threshold is exceeded, it is more important to ask a question regarding changes in the frequency. But when the exceedance of this fixed threshold becomes a normal occurrence in the future, this can lead to a saturation in the change of probability (Harrington and Otto, 2018a).
- If the impact of an event increases with the intensity of the event, it would be more relevant to examine changes in the magnitude.
- Finally, adaptation to climate change might change the relevant thresholds over time, although such aspects are still rarely integrated in the assessment of projected changes in extremes.

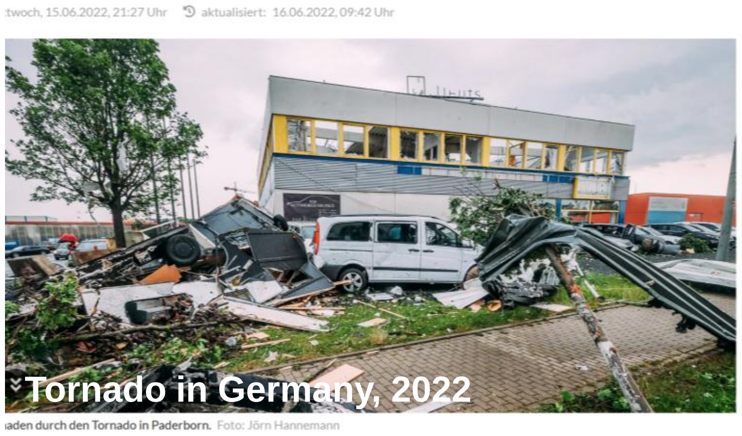
Human dimension

- AR6, Ch11

Beyond climate variables – impact and vulnerability

- «Every year, disasters related to weather, climate and water hazards cause **significant loss of life** and set back economic and social developments by years, if not decades.»

- «From 1970 to 2012, 8,835 disasters, 1.94 million deaths and US$ 2.4 trillion of **economic losses** were reported globally as a result of droughts, floods, windstorms, tropical cyclones, storm surges, extreme temperatures, landslides and wildfires, or by health epidemics and insect infestations directly linked to meteorological and hydrological conditions.»



Tornado in Germany, 2022

From WMO (2014) *Atlas Of Mortality And Economical Losses From Weather, Climate And Water Extremes (1970-2012)*


Floods in Switzerland, 2021

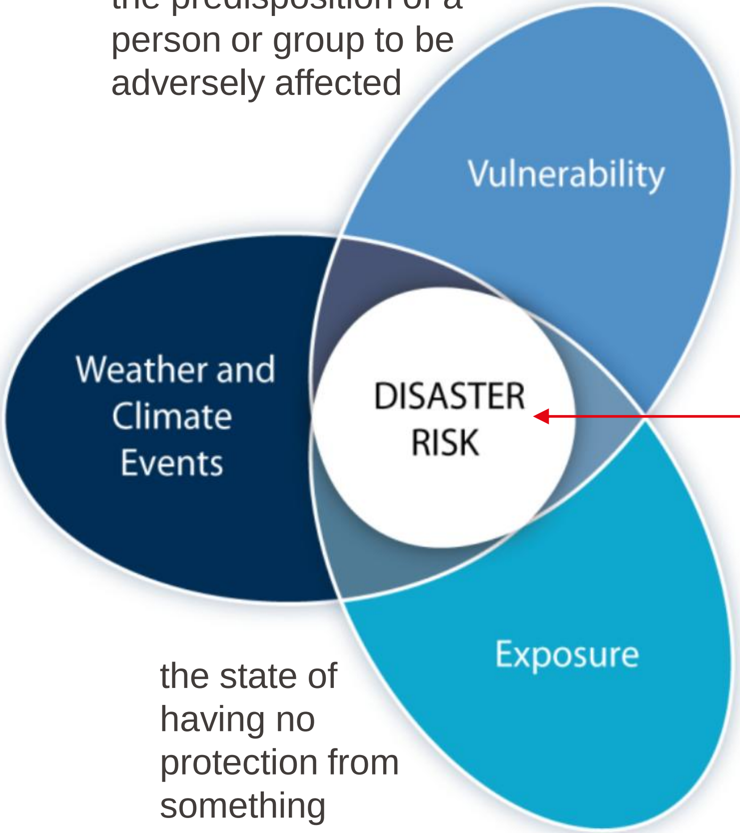

Fires in France, 2022

Beyond climate variables – impact and vulnerability

Socioeconomic development interacts with natural climate variations and human-caused climate change to influence disaster risk
→ There is a human dimension to the definition of extreme events.
→ The impact counts as well.

the predisposition of a person or group to be adversely affected

climate change-driven



the likelihood of severe alterations in the normal functioning of a community or society due to weather or climate events interacting with vulnerable social conditions

the state of having no protection from something harmful

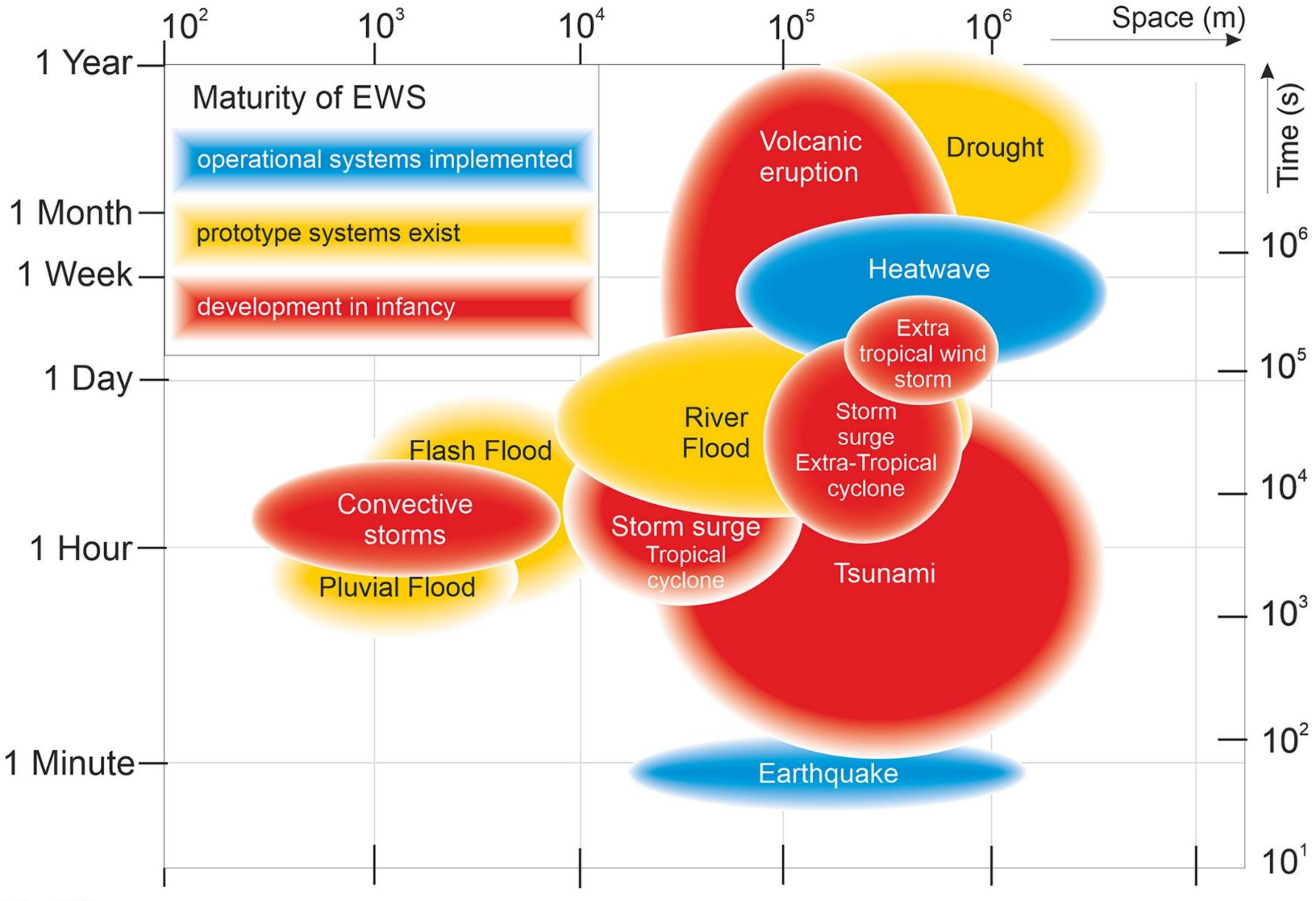
- https://www.ipcc.ch/site/assets/uploads/2018/03/IPCC_SREX_slide_deck-1.pdf, IPCC 2012

Compound Events

- Events that occur at the same time or in sequence (such as consecutive floods in the same region) and in the same geographic location or at multiple locations within a given country or around the world.
- May consist of multiple extreme events or of events that by themselves may not be extreme but together produce a multi-event occurrence.
- It is possible for the net impact of these events to be less than the sum of the individual events if their effects cancel each other out.
    - For example, increasing CO_2 concentrations and acceleration of the hydrological cycle may mitigate the future impact of extremes in gross primary productivity that currently impact the carbon cycle.
- From a risk perspective, the primary concern relates to compound extremes with additive or even multiplicative effects.
    - For instance, lack of precipitation early in the year combined with an atmospheric blocking event over western Russia in 2010 led to an extraordinary hot and dry summer, which induced widespread wildfires and air pollution ultimately causing more than 50,000 deaths and destroying 25% of Russian crops.
- Difficulty is to predict compound events to be prepared.

- https://science2017.globalchange.gov/chapter/15/; https://damocles.compoundevents.org/

Development of impact forecasting systems



- Opens new possibilities for coping with damaging events in the emergency phase
- Include exposure and vulnerability estimates
- Extending single-hazard to multihazard impact forecasts considering interactions between hazards and vulnerabilities is the next challenge

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020RG000704