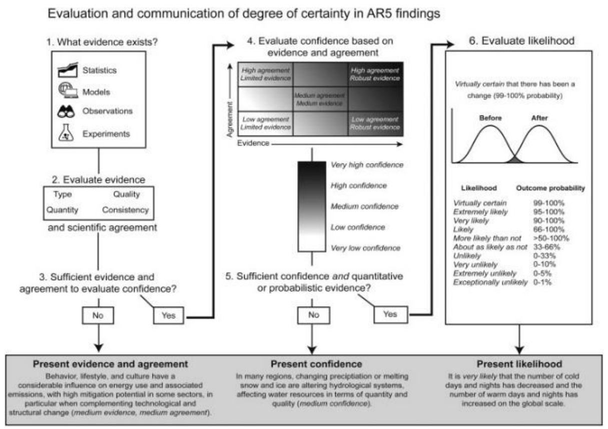
Recap from last week



Calibrated language of the IPCC reports on likelihood and confidence

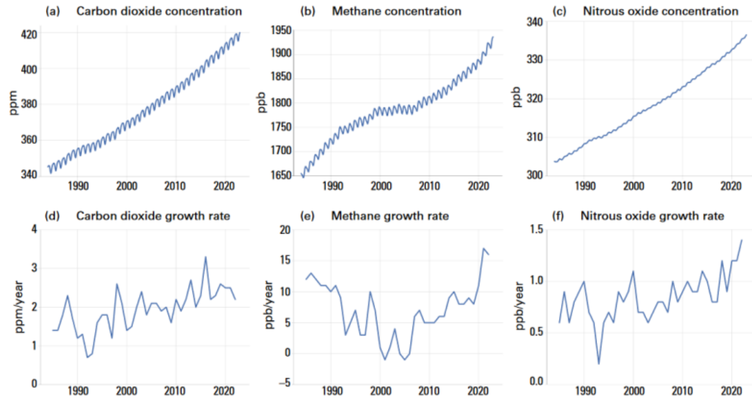
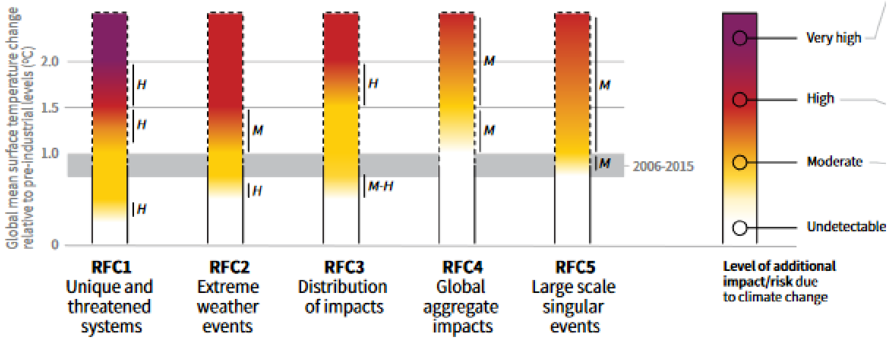


Figure 1. Top row: Monthly globally averaged mole fraction (measure of atmospheric concentration), from 1984 to 2022, of (a) CO_2 in ppm, (b) CH_4 in ppb and (c) N_2O in ppb. Bottom row: Growth rates representing increases in successive annual means of mole fractions for (d) CO_2 in ppm per year, (e) CH_4 in ppb per year and (f) N_2O in ppb per year.

Source: World Data Centre for Greenhouse Gases (WDCGG)

GHG concentrations and emission rates (!) are still growing.

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

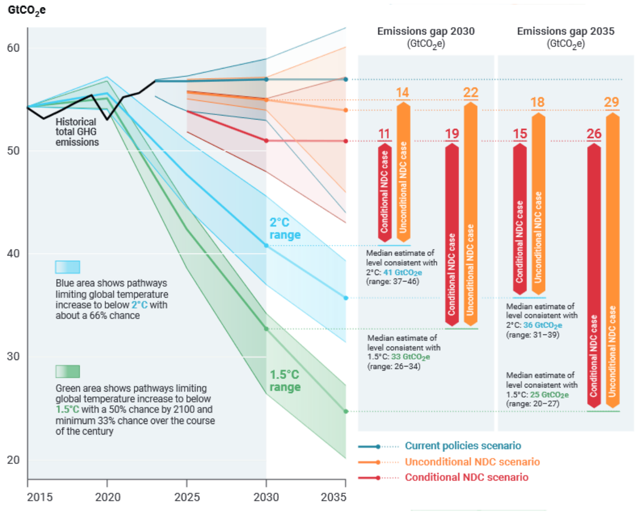


There are important differences between warming of 1.5°C or more: 5 reasons of concern include changed living conditions, extremes and tipping points.

Christiana Figueres: main author of the Paris Agreement

The Paris agreement uses nationally determined contributions as the main mechanism for carbon reduction.

Figure ES.3 Global GHG emissions under different scenarios and the emissions gap in 2030 and 2035



There is a gap between necessary carbon emission reduction and NDCs: Emissons Gap.

General outline

Basics

Present and future Climate change

Actions

No.	Date	Topics	Deadlines
1.	12.09.2024	Introduction	fill in Questionnaire in exercises (not graded)
2.	19.09.2024	Climate System, Radiation, Greenhouse effect	
3.	26.09.2024	Earth's energy balance, Radiative transfer,	
4.	03.10.2024	Aerosols & clouds, Radiative Forcing	Launch of poster assignment
5.	10.10.2024	Feedback mechanisms, Climate Sensitivity	
6.	17.10.2024	Emergent Constraints, Paleoclimate	submission of Poster proposal (01.11.2024)
7.	31.10.2024	Climate variability	
8.	07.11.2024	IPCC, present day climate change, Paris Agreement, Emissions Gap, COP	
9.	14.11.2024	**Extreme Events, COP29**	
10.	21.11.2024	Climate scenarios (RCPs, SSPs), Tipping elements	submission of Poster draft
11.	28.11.2024	Carbon budget, carbon offsets, metrics	submission of assignment (graded)
12.	05.12.2024	Regional climate change	
13.	12.12.2024	Mitigation and adaptation, Climate Engineering	**Poster Conference** (graded)
14.	19.12.2024	Recapitulation of key points, questions and answers session	fill in Questionnaire in exercises (not graded)

Extreme Events

April: Heat waves in India, Bangladesh, Thailand and Philippines

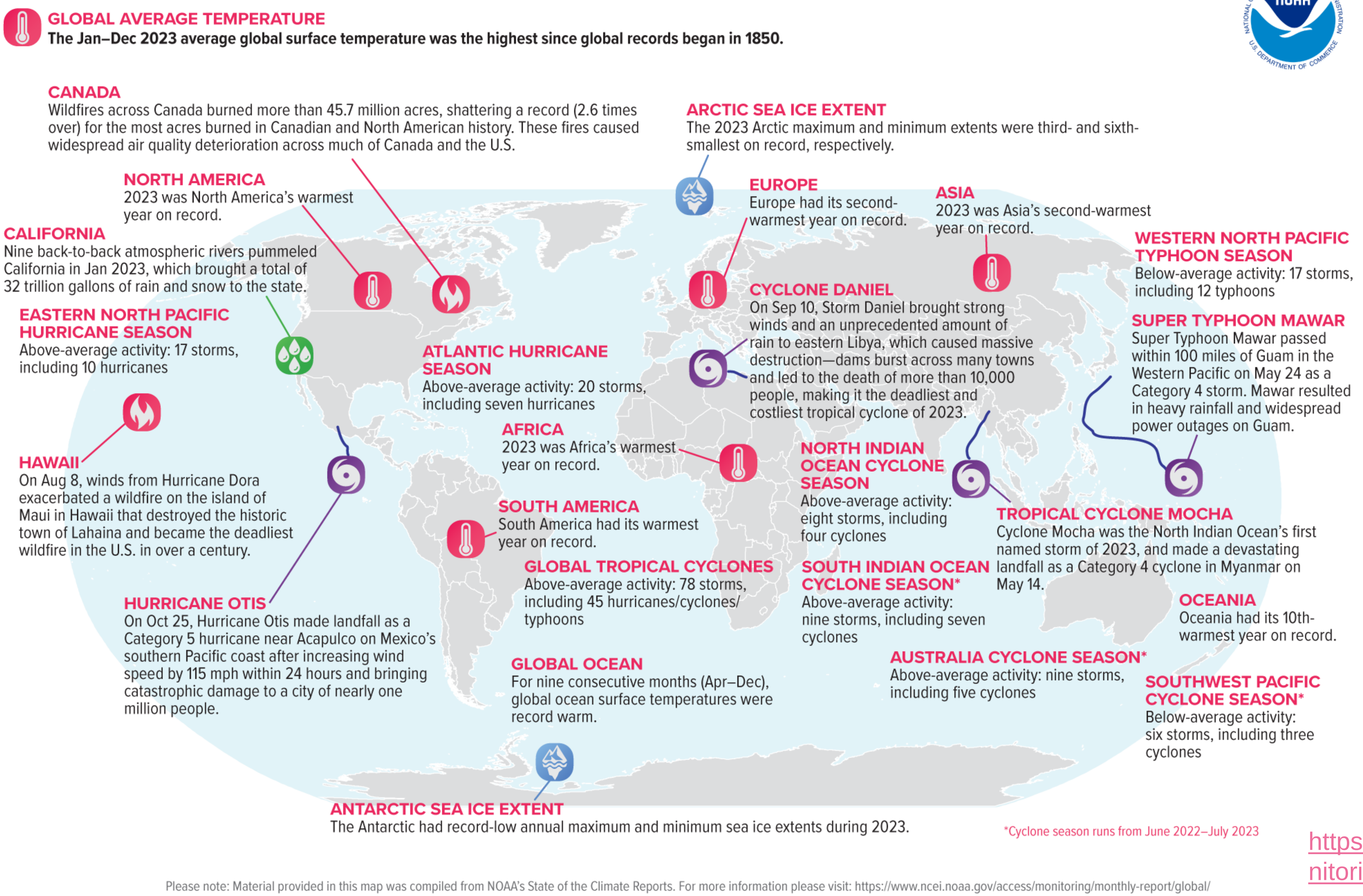
April - May: Record flooding in Brasil - up to half of the annual predicted rain fell in just 10 days

April : UAE flooding

March - May : Kenya flooding

May: Cyclone Remal – Bangladesh

Selected Significant Climate Anomalies and Events: Annual 2023



https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/202313

All these events have become more likely because of climate change.

Types of extreme events

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

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

What is an extreme event?

- Extreme event definition by Oxford Dictionary:
  - Extreme:
    - Reaching a high or the highest degree, very great
    - Not usual; exceptional
    - Very severe or serious
  - Event:
    - A thing that happens or takes place, especially one of importance

- Definition is not that straight forward.

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.

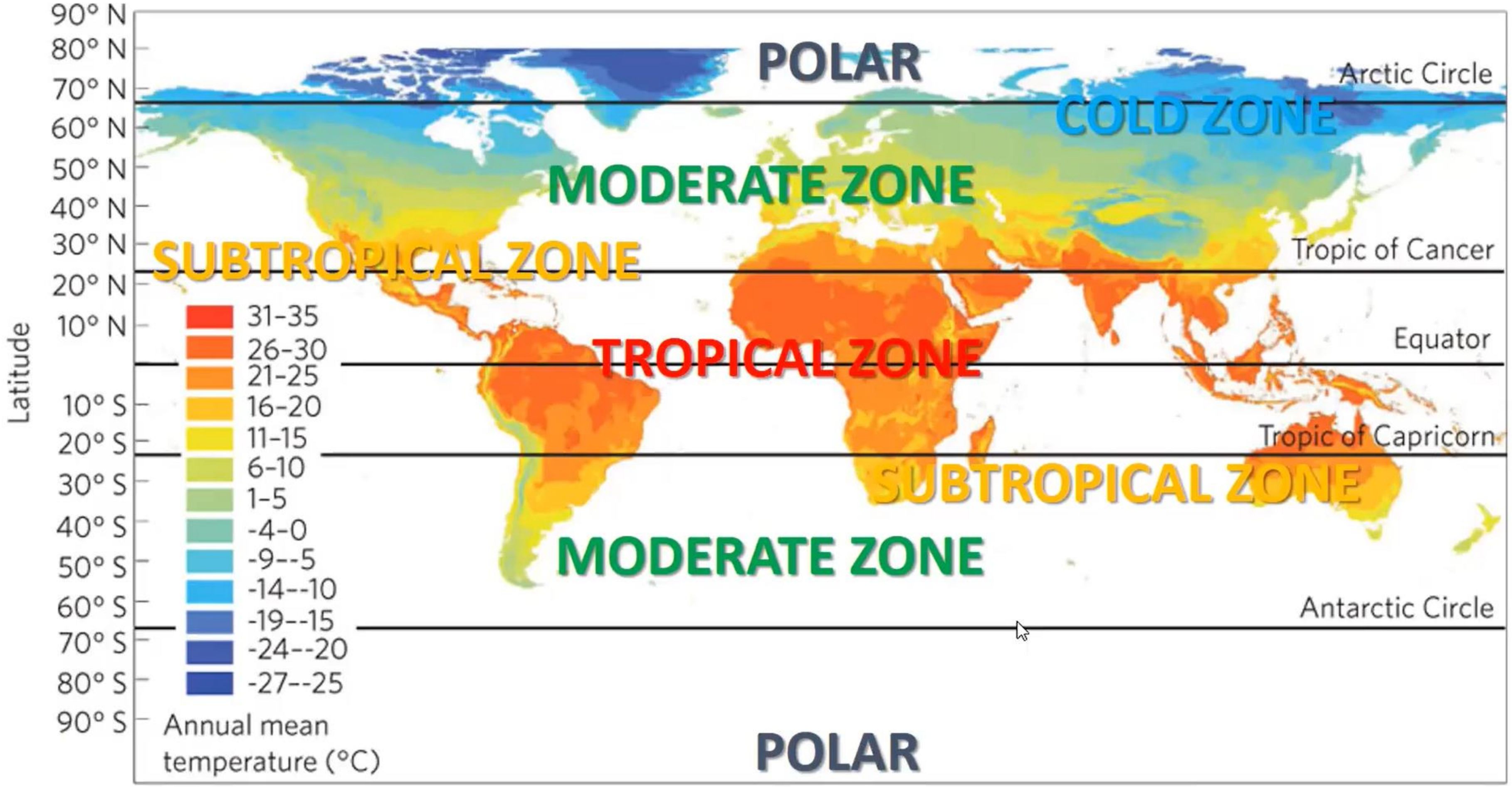
What is an extreme climate/weather event?

- 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)

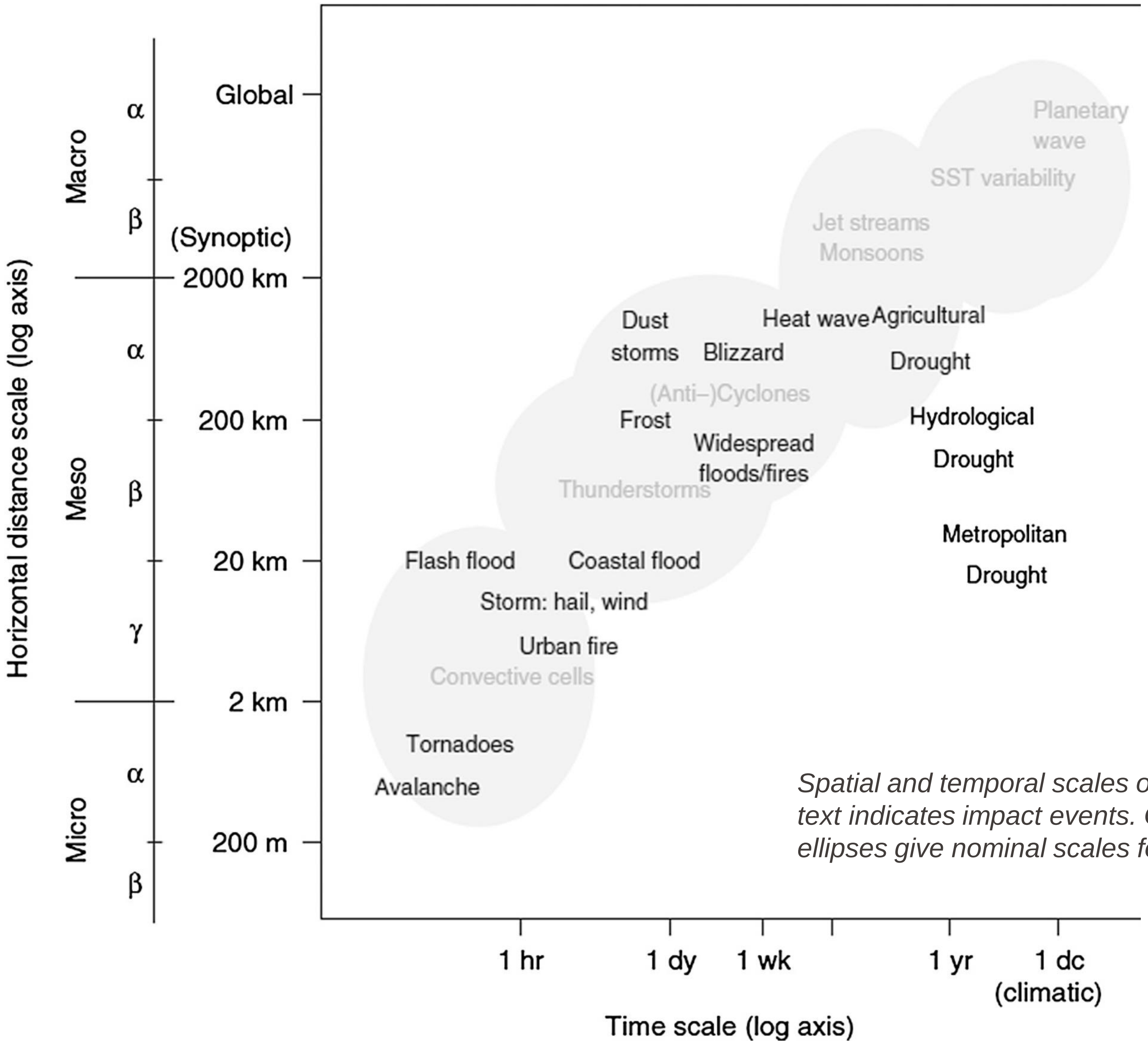
- Extremes in one location may be normal in another.

Climate zones – it's all relative



Saikkonen et al. NCC, 2012

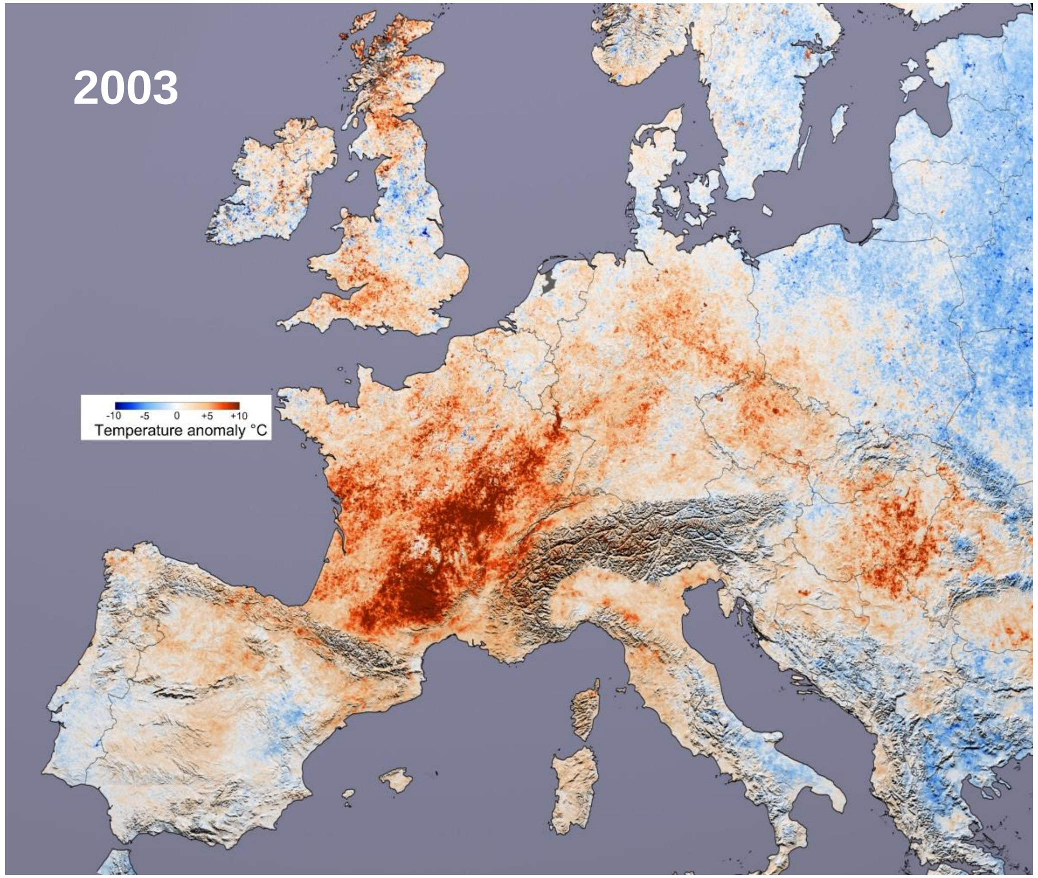
Spatial and temporal scales



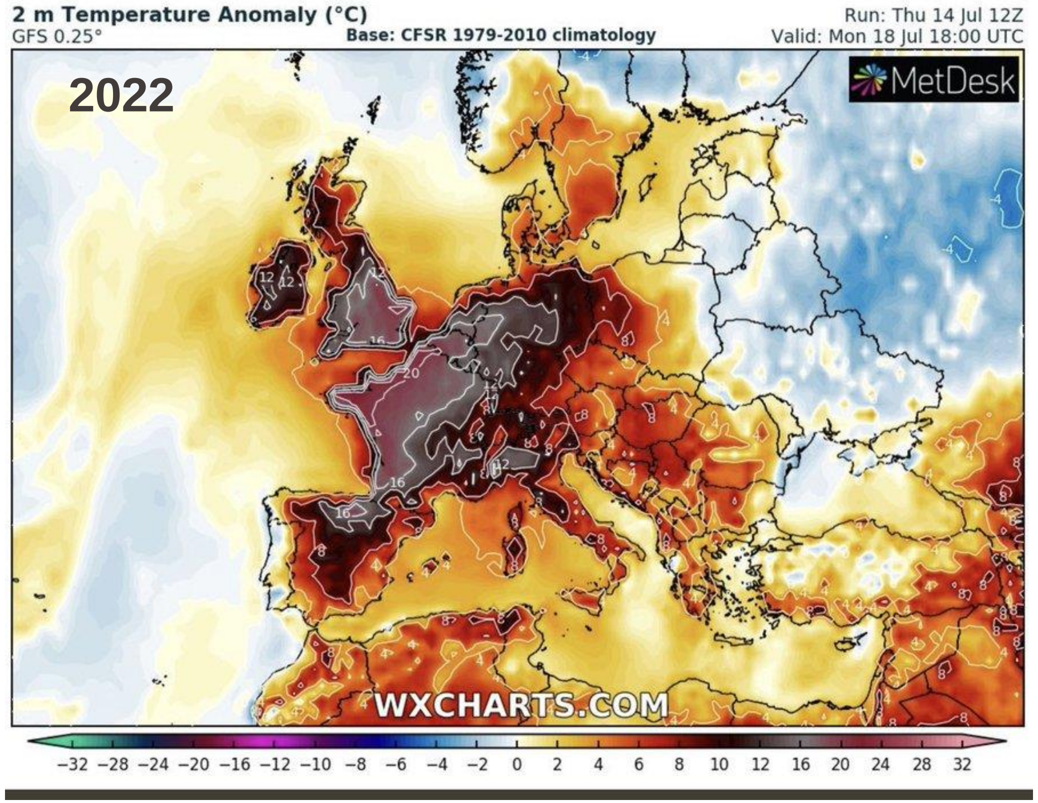
Spatial and temporal scales of typical events. Black text indicates impact events. Grey text and shaded ellipses give nominal scales for climatic events.

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

Spatial extent



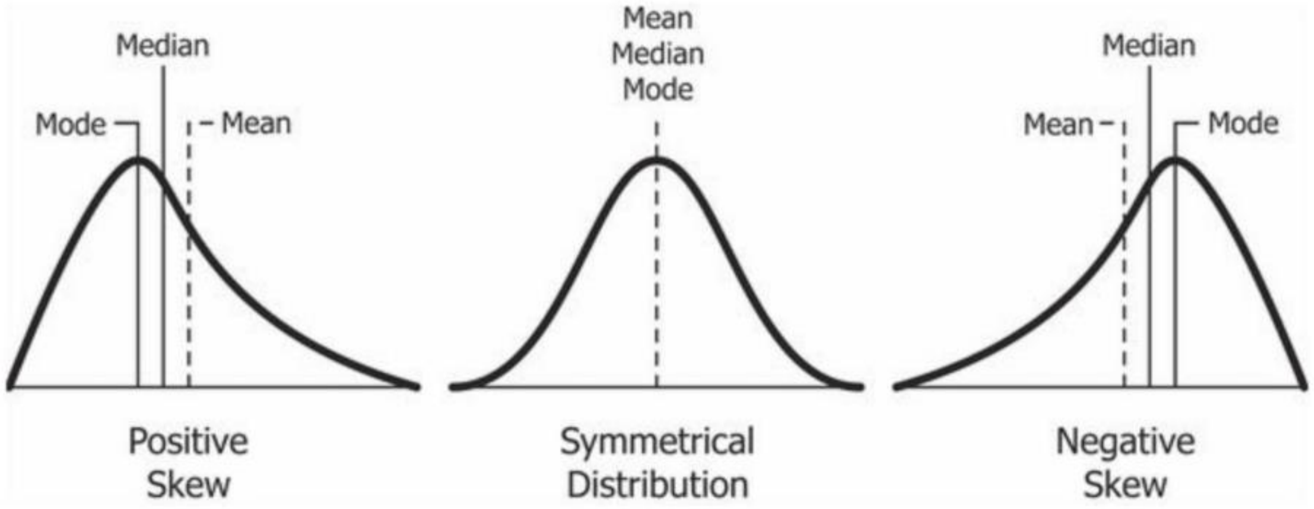
https://en.wikipedia.org/wiki/2003_European_heat_wave#/media/File:Canicule_Europe_2003.jpg



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

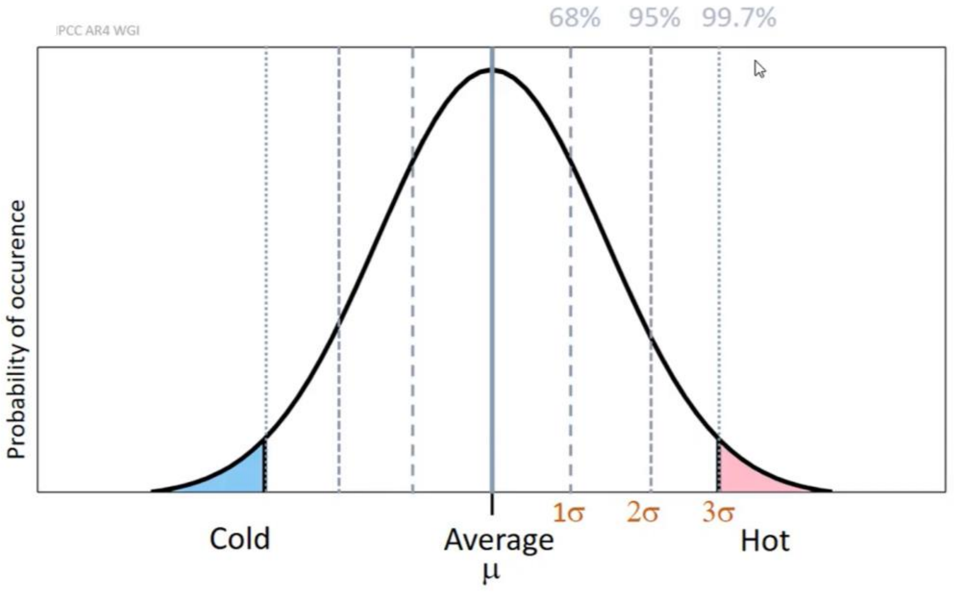
Climate value distributions

Precipitation **Temperature**

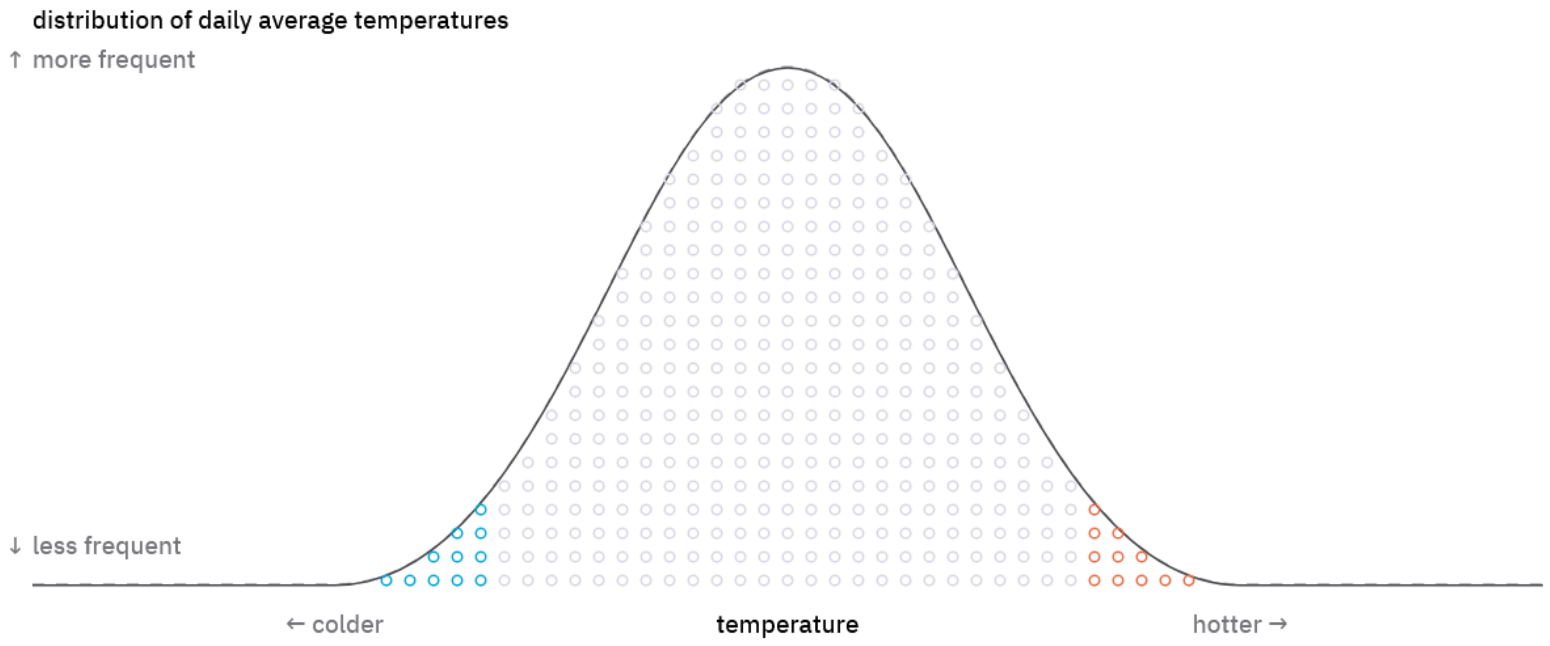


[Wikipedia]

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



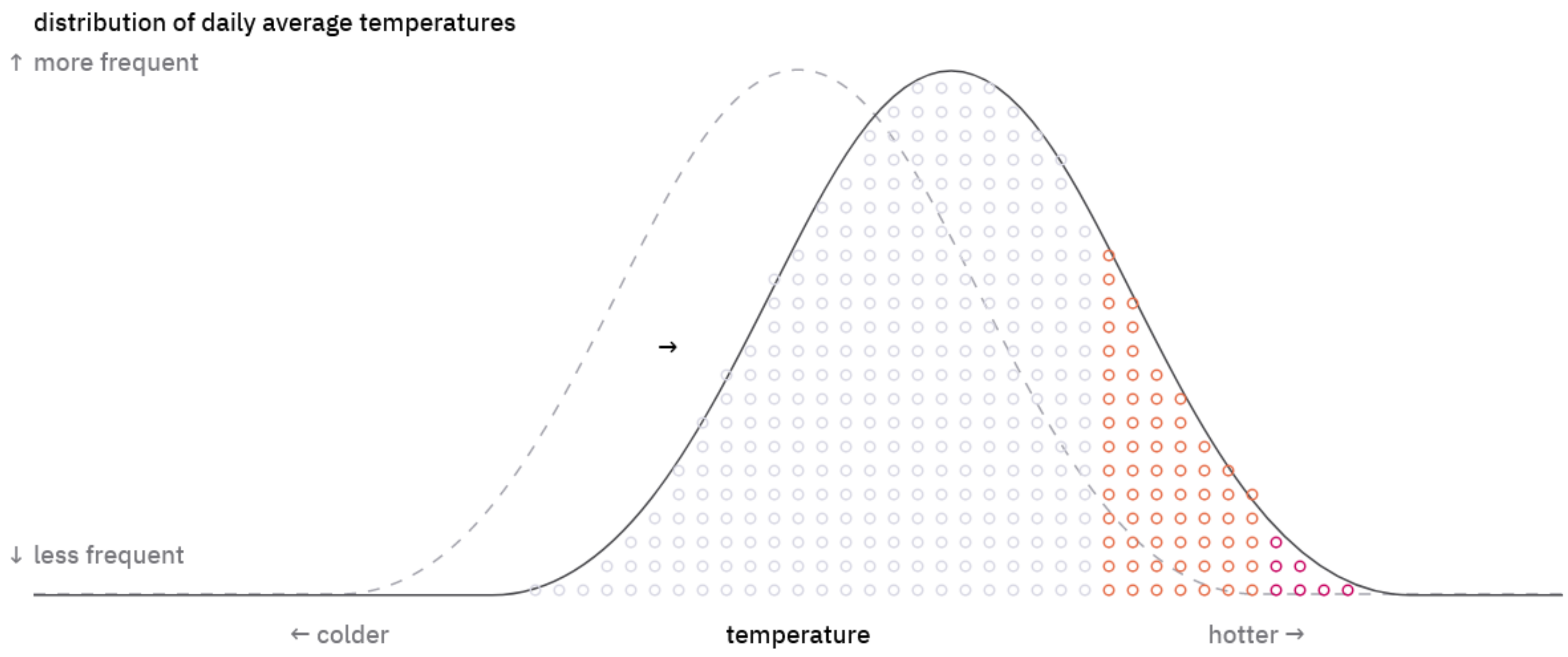
Climate extremes in a changing climate: «old climate»



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

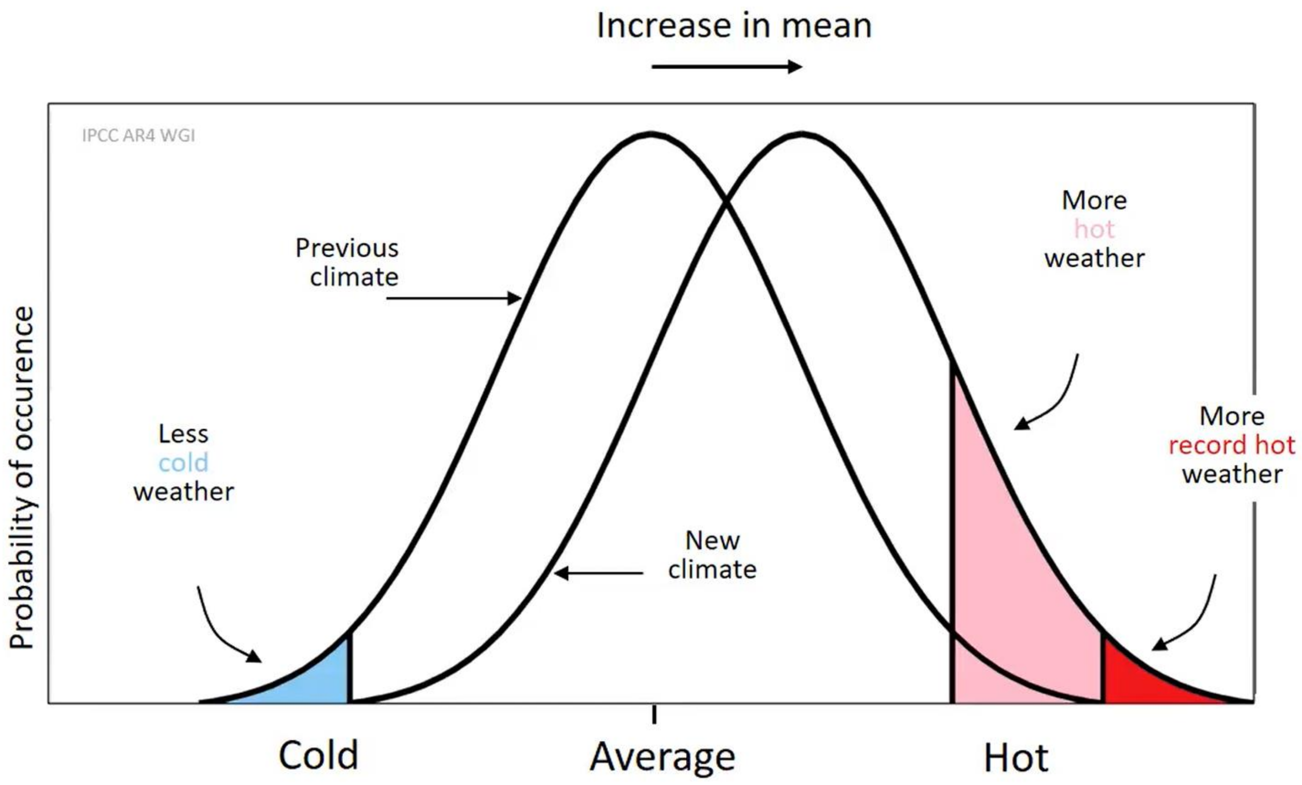


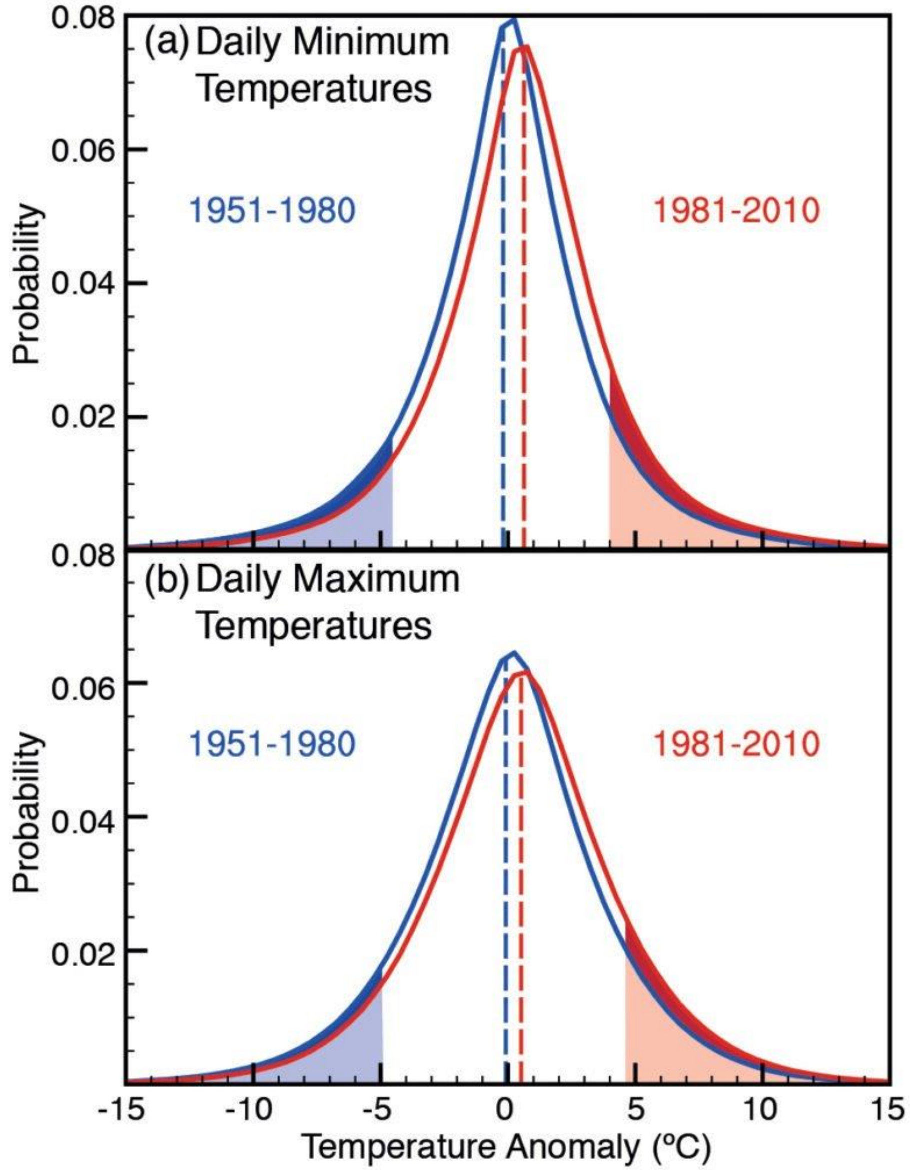
Under climate change, the mean temperature rises, and the distribution shifts to higher temperatures. Hot days that have been rare in the past occur now more frequently and reach even higher temperatures.

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

Climate extremes in a changing climate

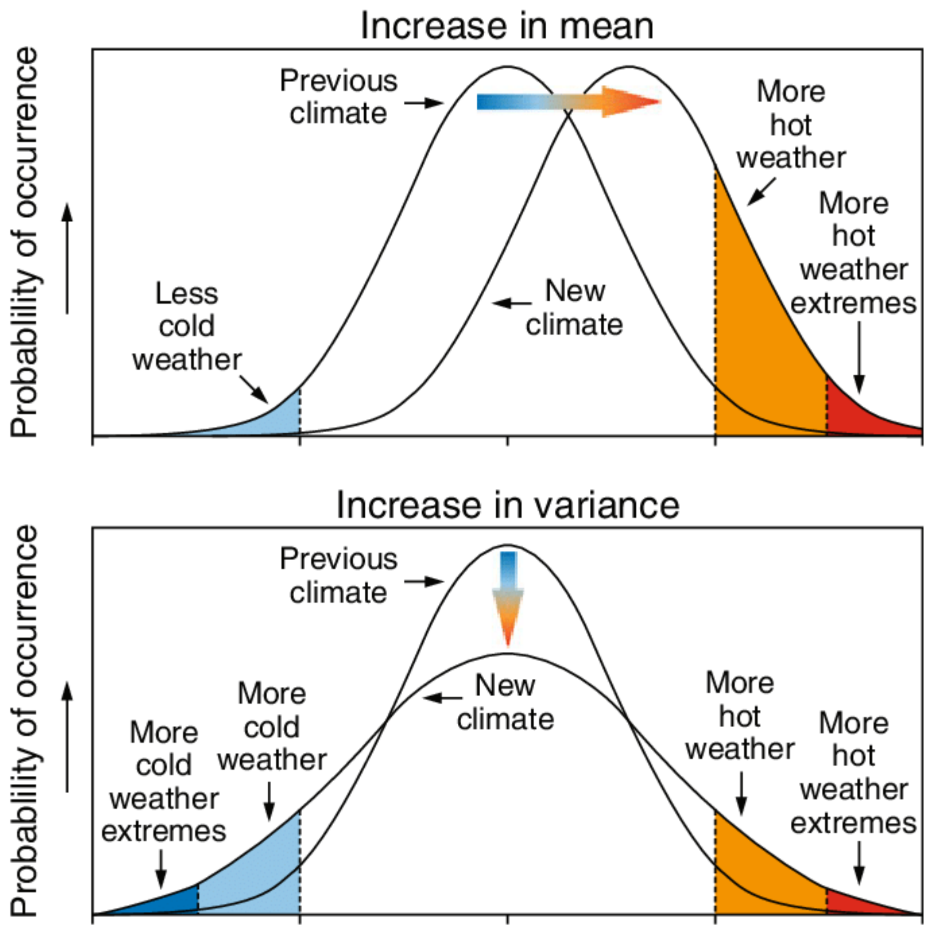
IPCC AR5 FAQ2.2

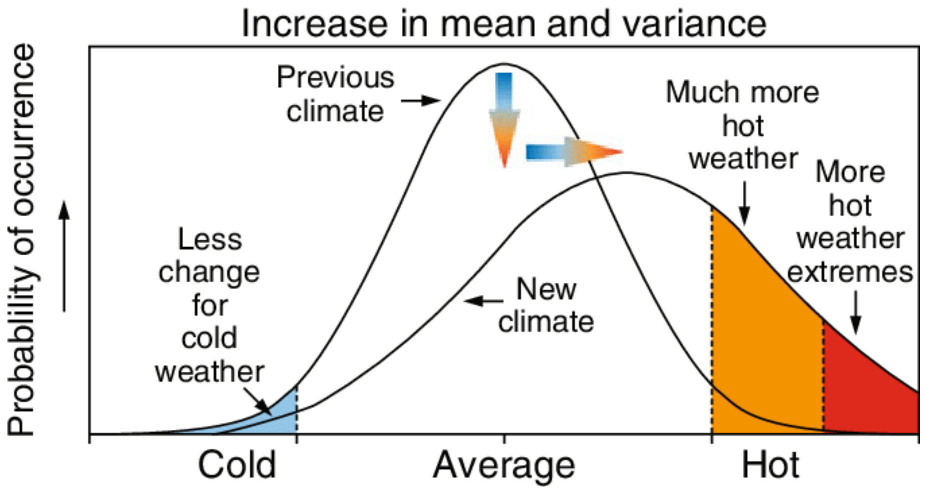


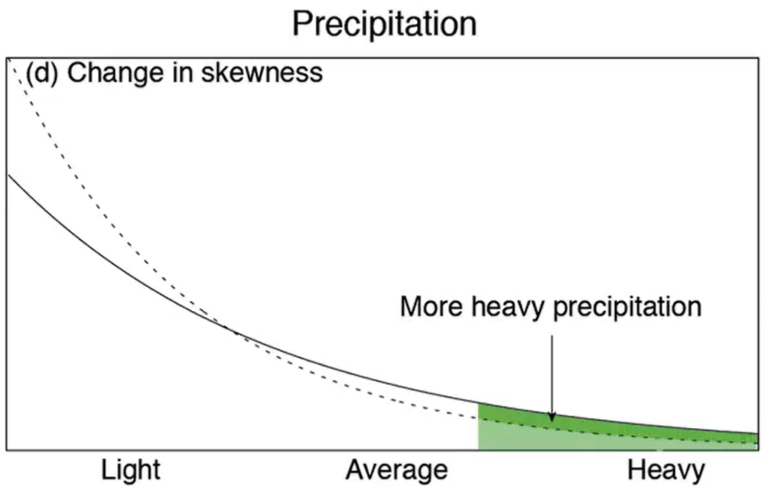


FAQ 2.2, Figure 1 | Distribution of (a) daily minimum and (b) daily maximum temperature anomalies relative to a 1961–1990 climatology for two periods: 1951–1980 (blue) and 1981–2010 (red) using the HadGHCND data set. The shaded blue and red areas represent the coldest 10% and warmest 10% respectively 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





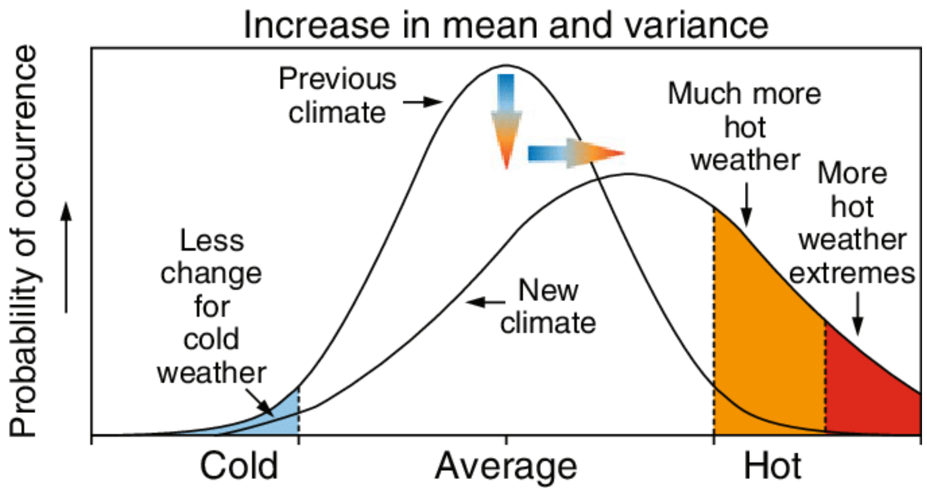


Distribution has a different shape for precipitiation. More skewed.

- 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

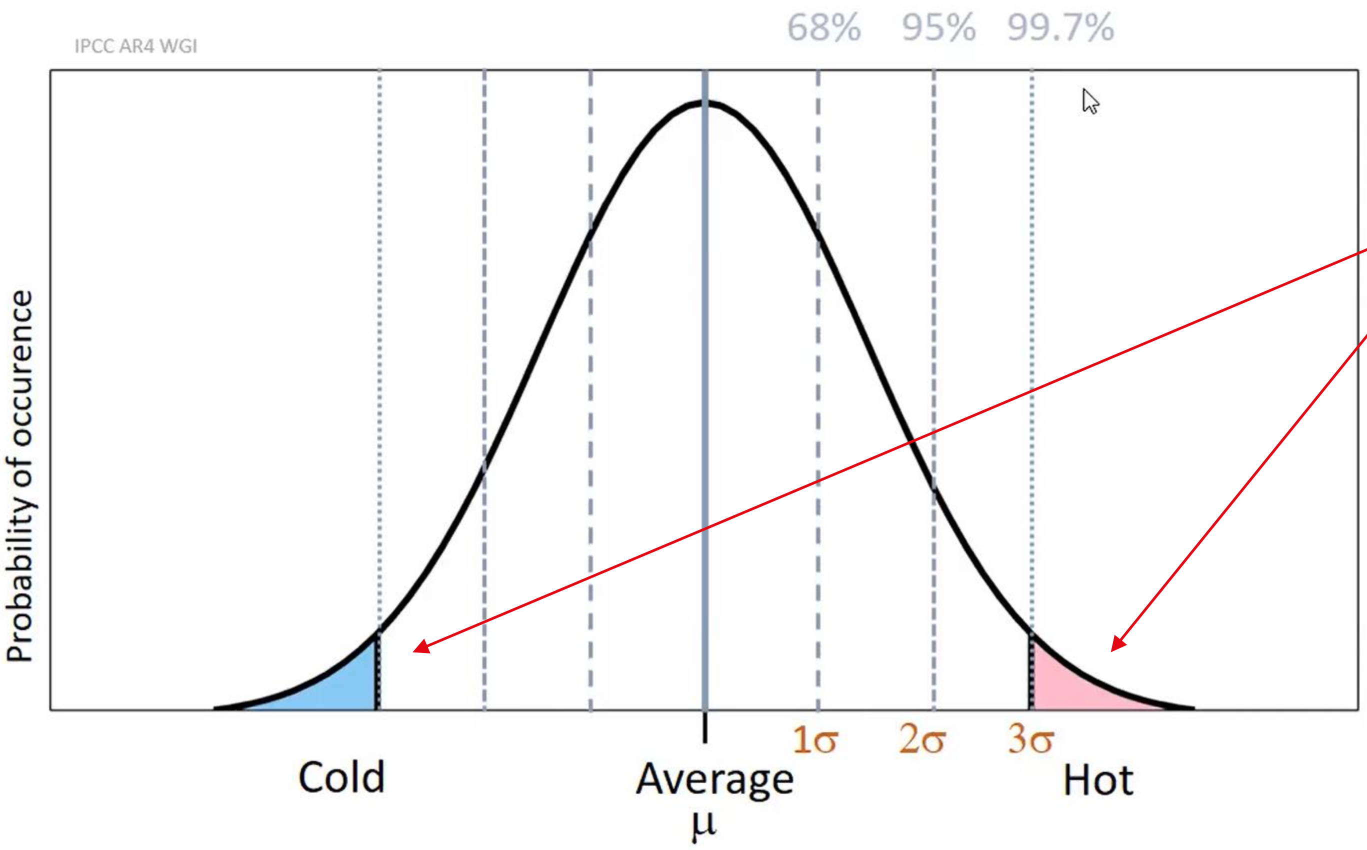


Finding a general definition

- **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).

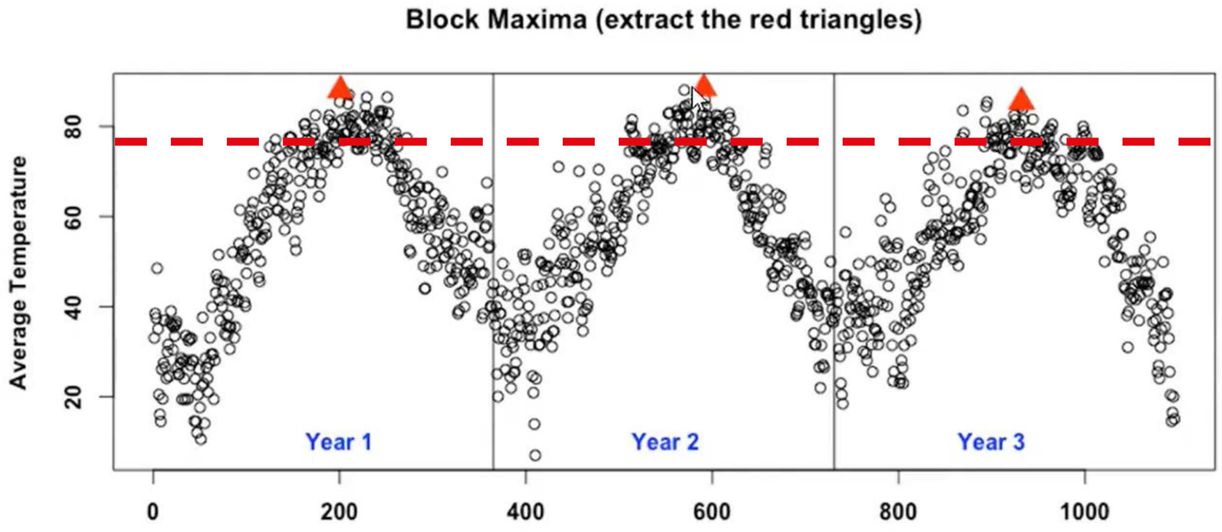
Fitting an extreme value distribution to climate data

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

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

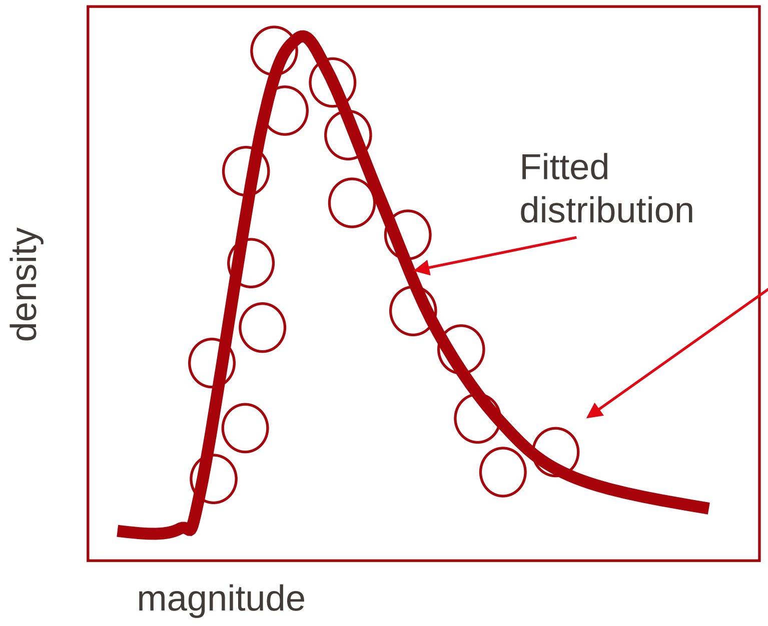
1. **Block maxima (maybe too little data)**
2. **Beyond a threshold (perhaps too many data to fit extreme value distribution)**

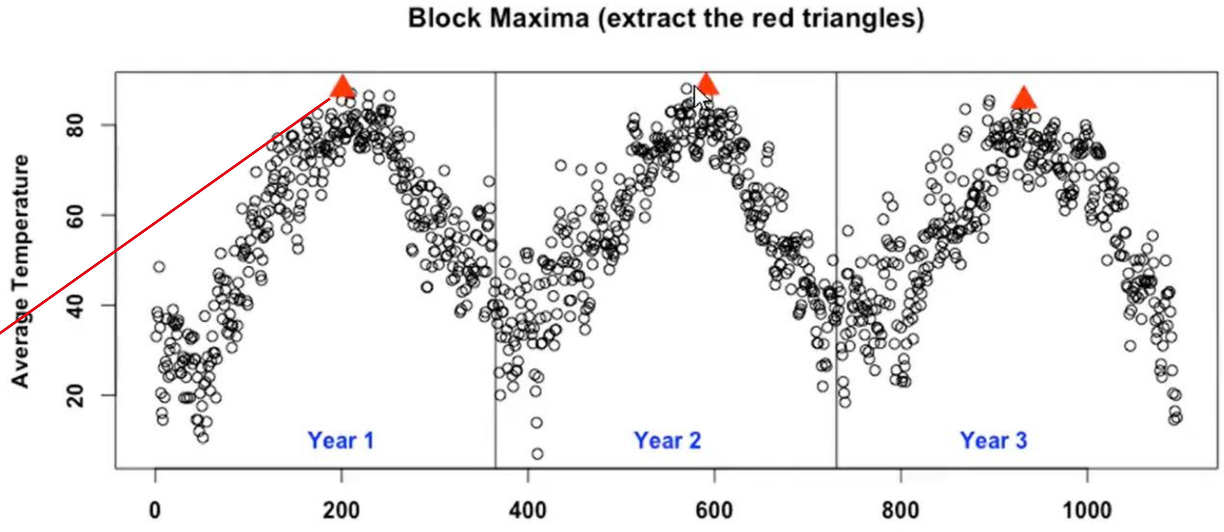


Adapted from and courtesy of J. Sillmann
http://www.dataanalysisclassroom.com/lesson60/

Fitting the extreme value distribution

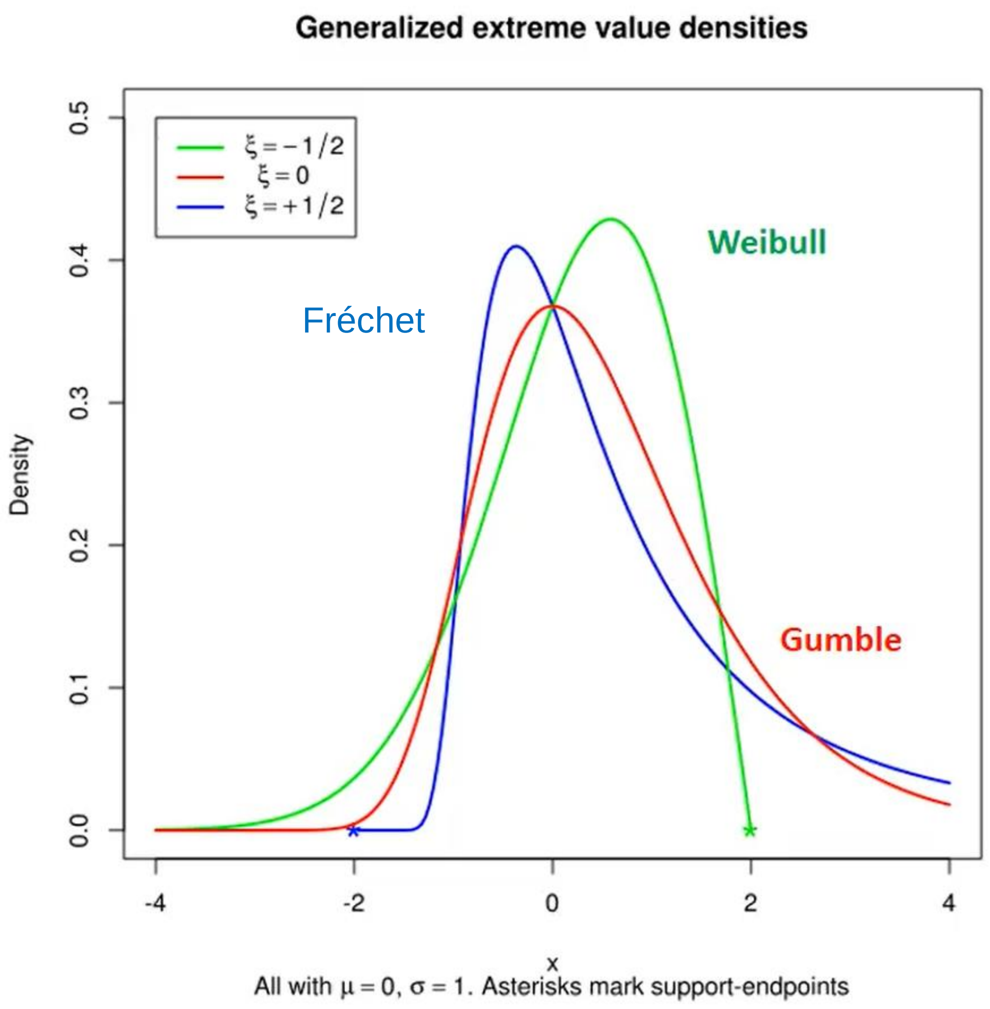
Generalized extreme value distribution





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)

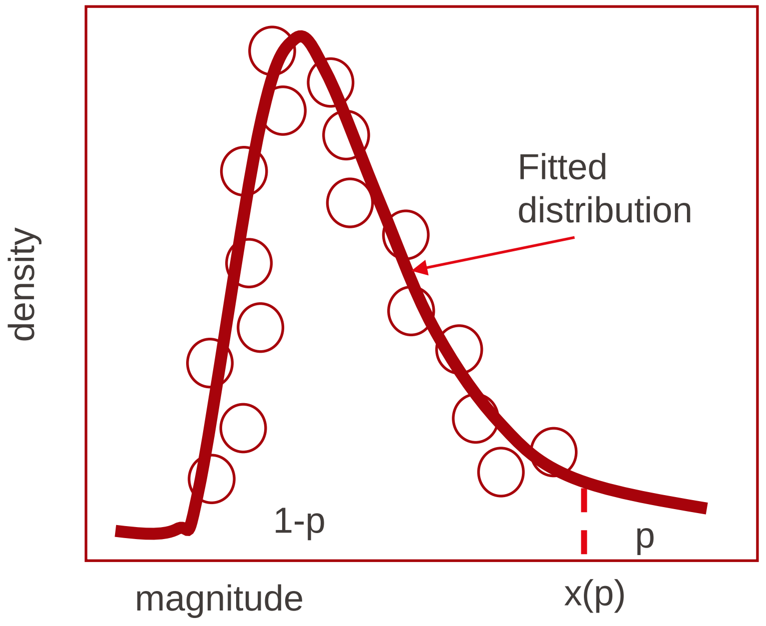
Coles, Stuart (2001). An Introduction to Statistical Modeling of Extreme Values. Springer-Verlag. ISBN 1-85233-459-2.

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

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



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

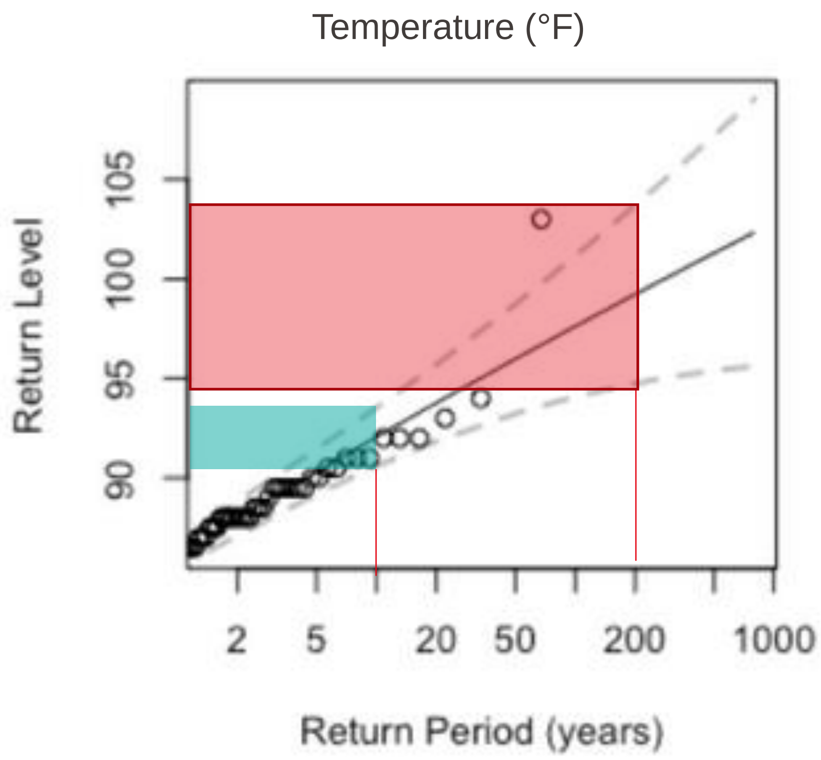
For example, if **p = 0.01**, then the return period is **T = 100 years**.

event x has probability p; x(p)

Adapted from and courtesy of J. Sillmann

Return levels

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



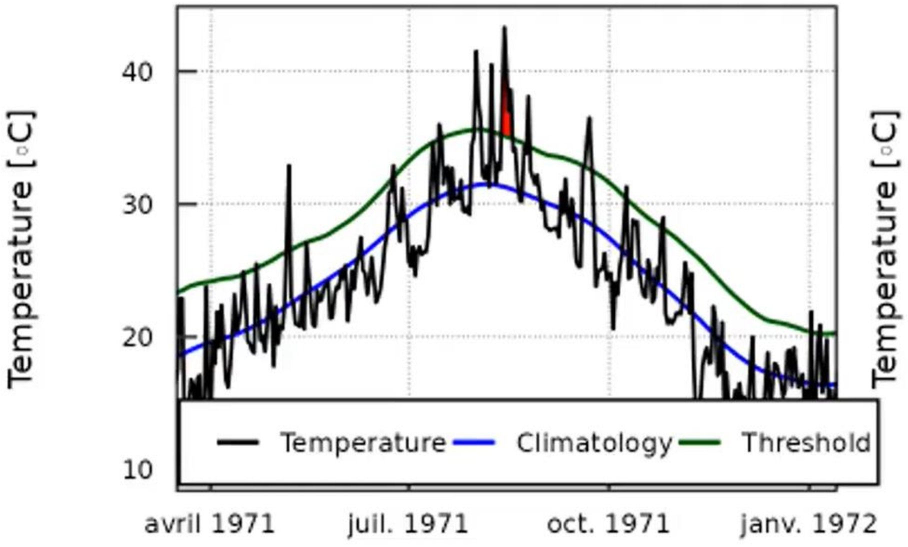
Uncertainty becomes larger for longer return periods
Also climate will change over longer time horizons (not stationary climate). This has to be taken into account.

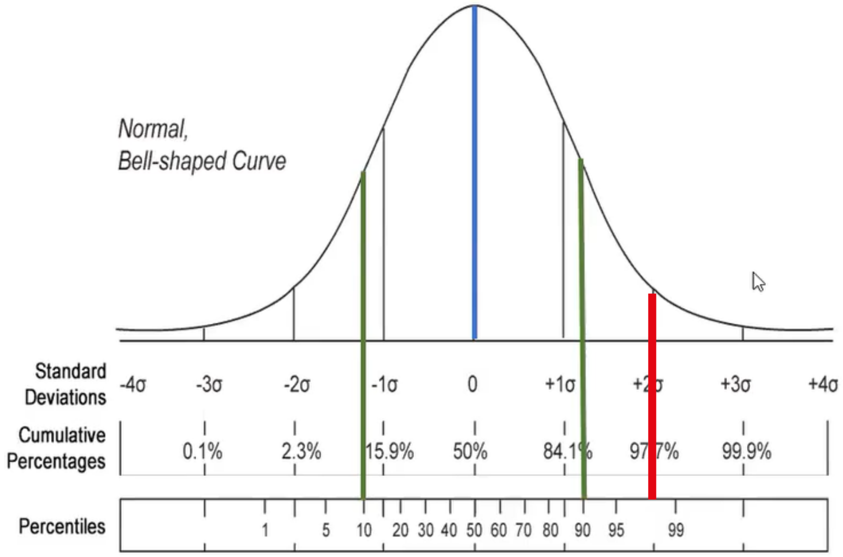
Finding a general definition

- **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





Indices for Climate Extremes

Annex VI — **Climatic Impact-driver and Extreme Indices**

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

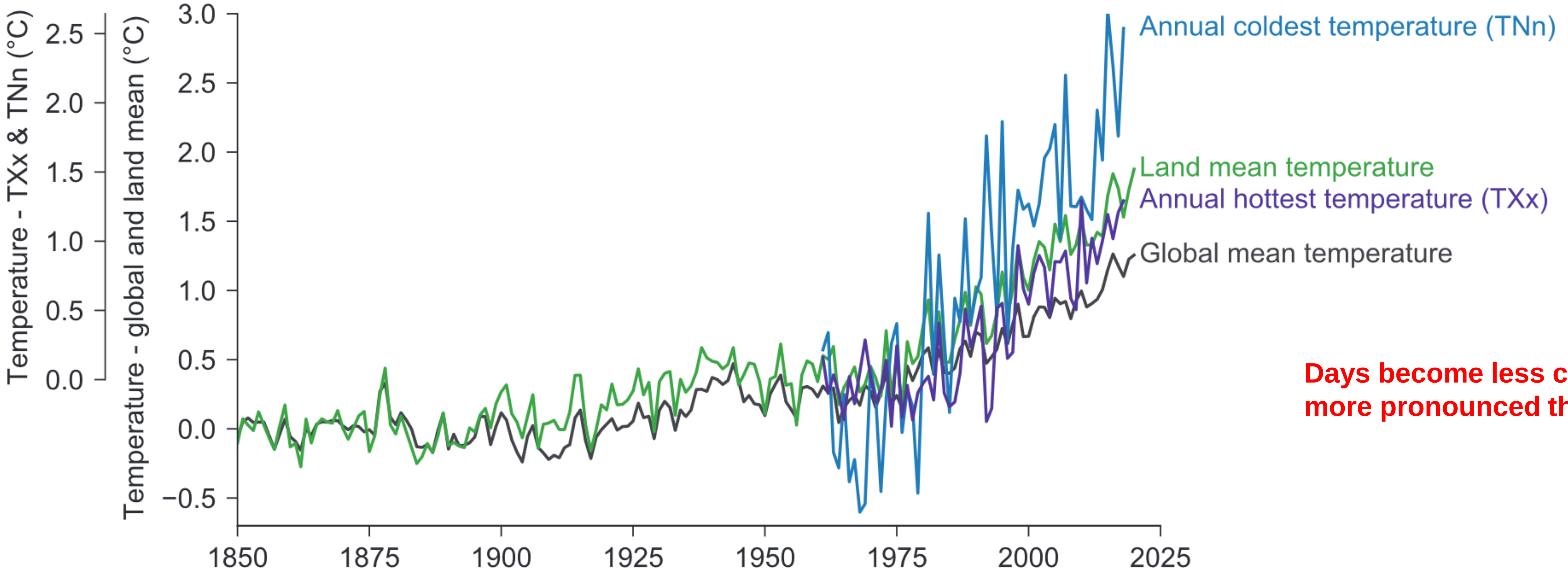
Extreme	Label	Index Name	Units	Variable
Temperature	TXx	Monthly maximum value of daily maximum temperature	°C	Maximum temperature
	TXn	Monthly minimum value of daily maximum temperature	°C	Maximum temperature
	TNn	Monthly minimum value of daily minimum temperature	°C	Minimum temperature
	TNx	Monthly 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

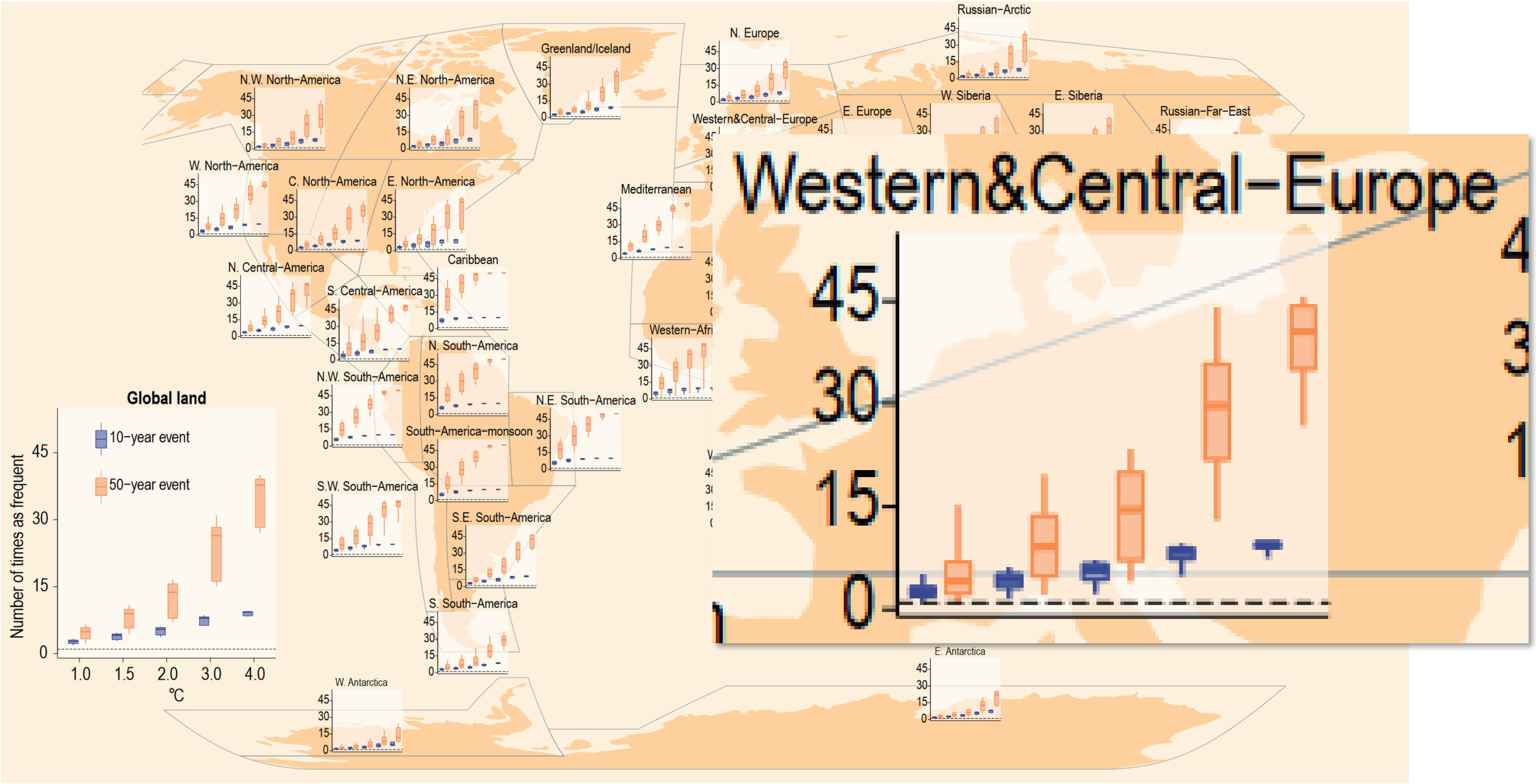


Figure 11.6 | Projected changes in the frequency of extreme temperature events under 1°C, 1.5°C, 2°C, 3°C, and 4°C global warming levels relative to the 1850–1900 baseline. Extreme temperatures are defined as the maximum daily temperatures that were exceeded on average once during a 10-year period (10-year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

All these events have become more likely because of climate change.

How can we be sure?

Extreme Event Attribution

- The chaotic nature of weather means that it is generally impossible to say, for any specific event, that it would not have occurred in the absence of human influence on climate.
- Science of **Probabilistic Even Attribution** has emerged in the last 20 years to determine the **attributable risk**: quantifying whether and how much past emissions have contributed to the probability of an extreme event occurring.
- Extreme Event Attribution studies compare how often a particular extreme weather event occurs in model experiments representing the **"world as it is"** (with human influence on climate) with how often the same type of event occurs in experiments representing the **"world that might have been"** (with the estimated impact of human influence on climate removed, allowing for uncertainty in this impact).

Factual and Counterfactual model simulations

"world as it is"

"world that might have been" without fossil fuel emissions

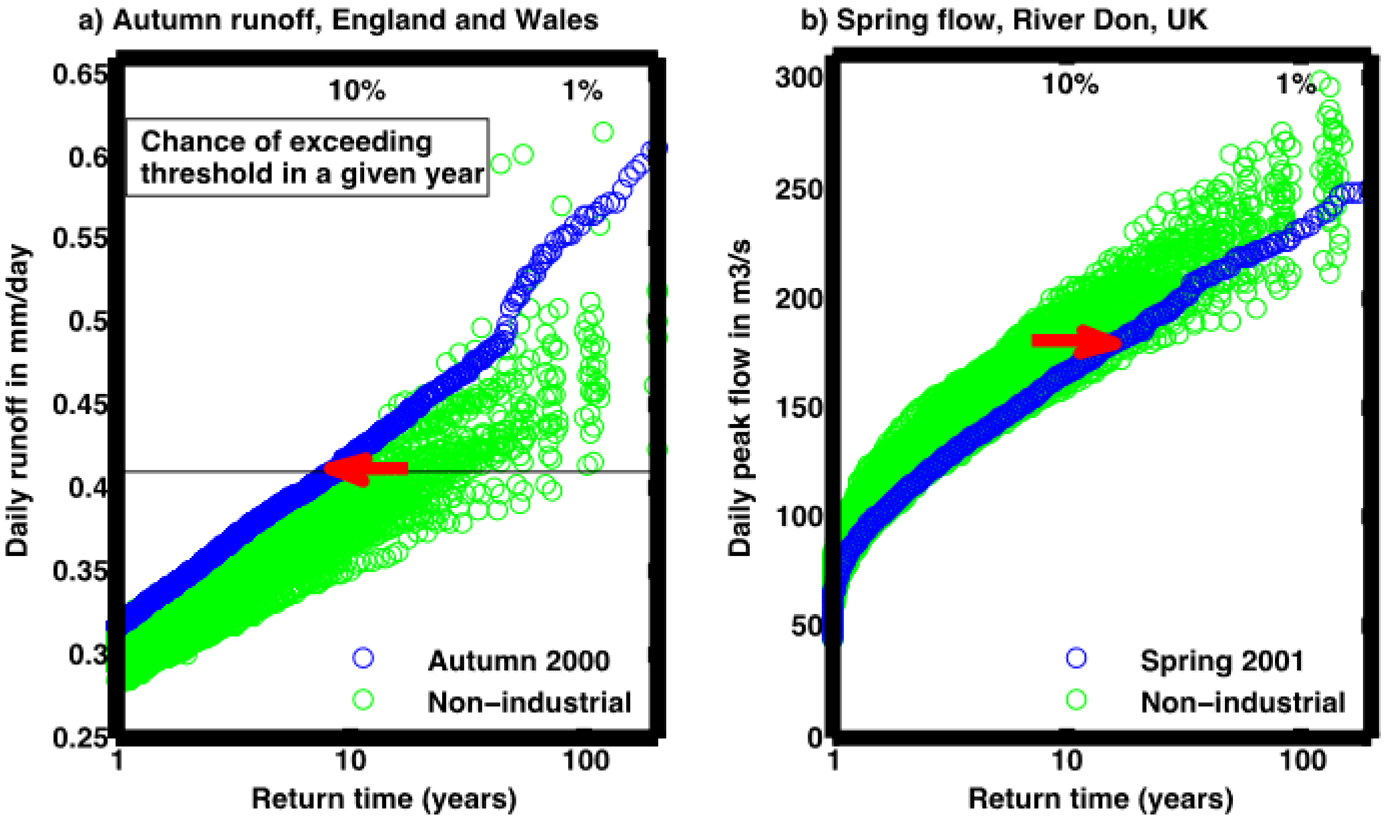


Figure 1 adapted from Figure 10.18 IPCC AR5 WG1 chapter 10.6.
Return times of run-off (an indication of flooding) for simulations of the **"world as it is" (blue)** compared to **the "world that might have been"** without anthropogenic GHG emissions (green). Red arrow shows **the tendency of change** in the event frequency.

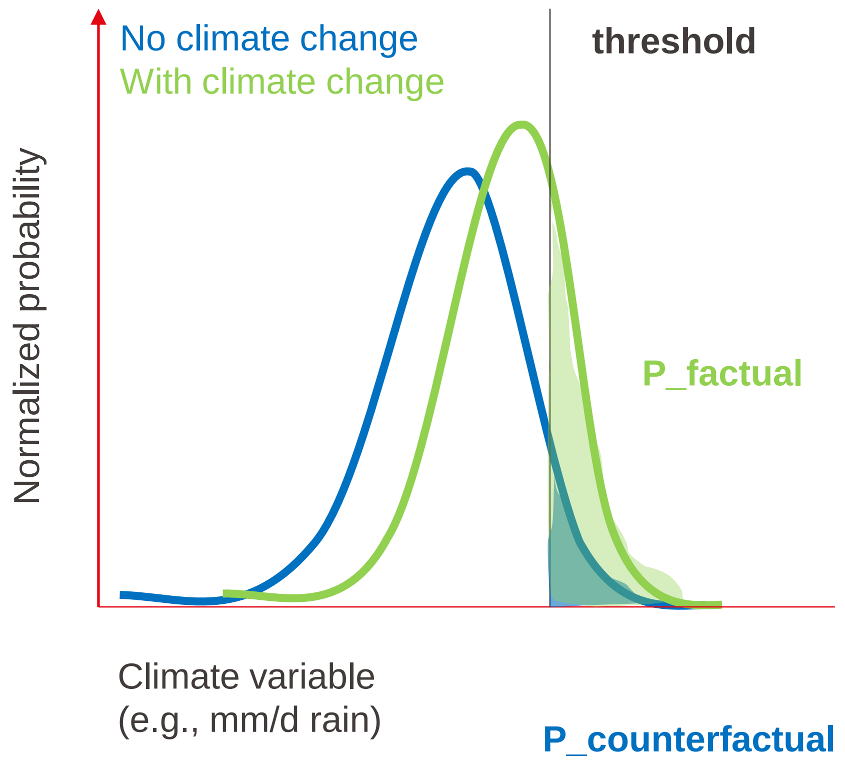
Panel (a) is for Autumn 2000 in England and Wales with the black line showing the threshold exceeded in observations
and panel (b) is for a different season and catchment.

Worsening (roughly by a factor 2)

Aleviation:
less probability of extreme event

- https://unfccc.int/files/adaptation/workstreams/loss_and_damage/application/pdf/attributingextremeevents.pdf

How do we assess the risk that the extreme event causes due to climate change?



- P_actual > P_counterfactual
- Probability ratio:
  P_actual/P_counterfactual > 1
- Fraction of attributable risk (FAR)=
  1- p_counterfactual/p_actual

- Example
  - P_actual/p_counterfactual = 2
  - FAR = 1-0.5=0.5
  - → 50 % of the event can be attributed to climate change

EPFL

Steps of a scientific probability attribution study

1. measuring the magnitude and frequency of a given event based on observed data,
2. running computer models that are compared to and verified with the observational data,
   1. Can the model in principle represent the extremes of interest?
   2. Are the statistics of the modeled extreme events compatible with the statistics of the observed extremes?
   3. Is the meteorology driving these extremes realistic?
      → gaining trust in the model
3. running the same validated models on the counterfactual scenario with no climate change, and
4. using statistics (see previous slide) to analyze the differences between the second and third steps, thereby measuring the direct effect of climate change on the studied event.

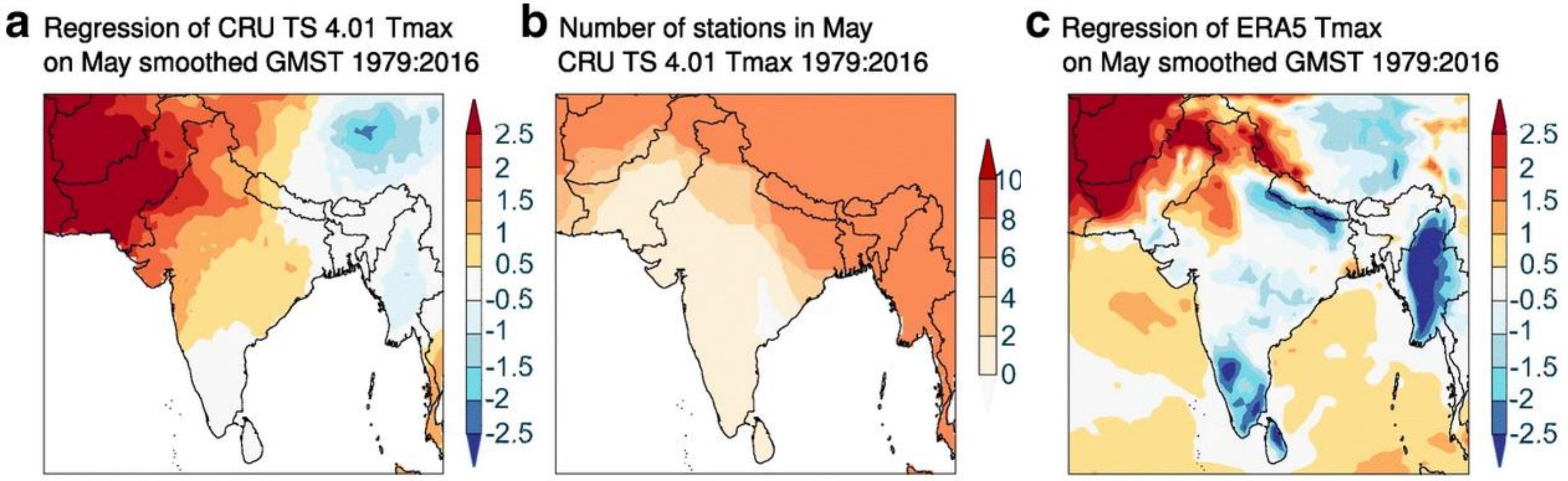
EPFL

Pitfalls of extreme event attribution

- Need of complete data series, too big gaps will introduce biases.
- Also gridded data from observations (interpolated between stations) can invoke biases.

Gridded and interpolated data, based on a few stations only, or even no station data

Data set based on numerical model with observational data integrated → gives a much more realistic view of the situation



a Trend of May maximum temperature in South Asia 1979–2016 in the CRU TS 4.01 dataset. **b** Number of stations used to estimate the temperature at each grid point in CRU TS 4.01. **c** Trend of May maximum temperatures in the ERA5 reanalysis

Floods in India in May 2016

- https://link.springer.com/article/10.1007/s10584-021-03071-7

Current developments in extreme event attribution

- The **World Weather Attribution (WWA)** collaboration has over the last 5 years developed a methodology to answer these questions in a scientifically rigorous way in the immediate wake of the event when the information is most in demand. → 8 Step procedure (see exercises)
- Next step: **Extreme Event Impact Attribution** (as opposed to risk or probability)
  - The methods of extreme event attribution (EEA) that quantify the extent to which climate change affected specific recent extreme weather events in the past 20 years have been combined more recently with socio-economic impact data to quantify extreme weather's impacts attributable to climate change.
  - The EEIA "algorithm" can be divided into the EEA part (the climate science component) and the impact analysis (the socio-economic component, including potentially human and environmental impacts). The EEA component is used to determine the change in the probability or the intensity of a well-defined extreme weather event (e.g., the rainfall in a particular location and period) as a consequence of climate change. The impact part then links this change to the event's observed impacts (e.g., mortality associated with the event) to attribute a fraction of the total impact of the event to anthropogenic climate change causes.

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.»

twoch, 15.06.2022, 21:27 Uhr aktualisiert: 16.06.2022, 09:42 Uhr

Tornado in Germany, 2022

aden durch den Tornado in Paderborn. Foto: Jörn Hannemann

Floods in Switzerland, 2021

Fires in France, 2022

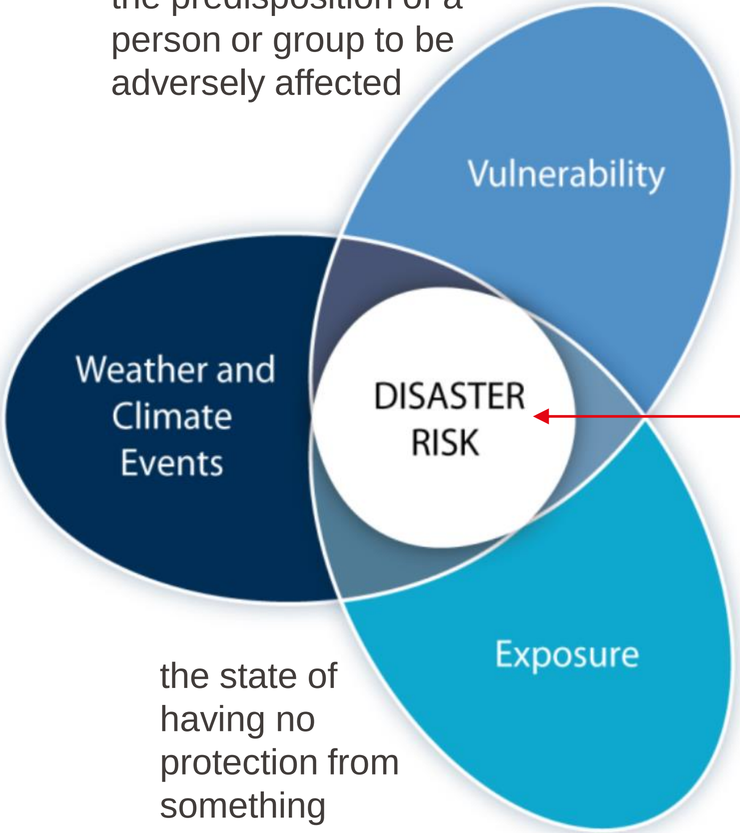
From WMO (2014) *Atlas Of Mortality And Economical Losses From Weather, Climate And Water Extremes (1970-2012)*

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

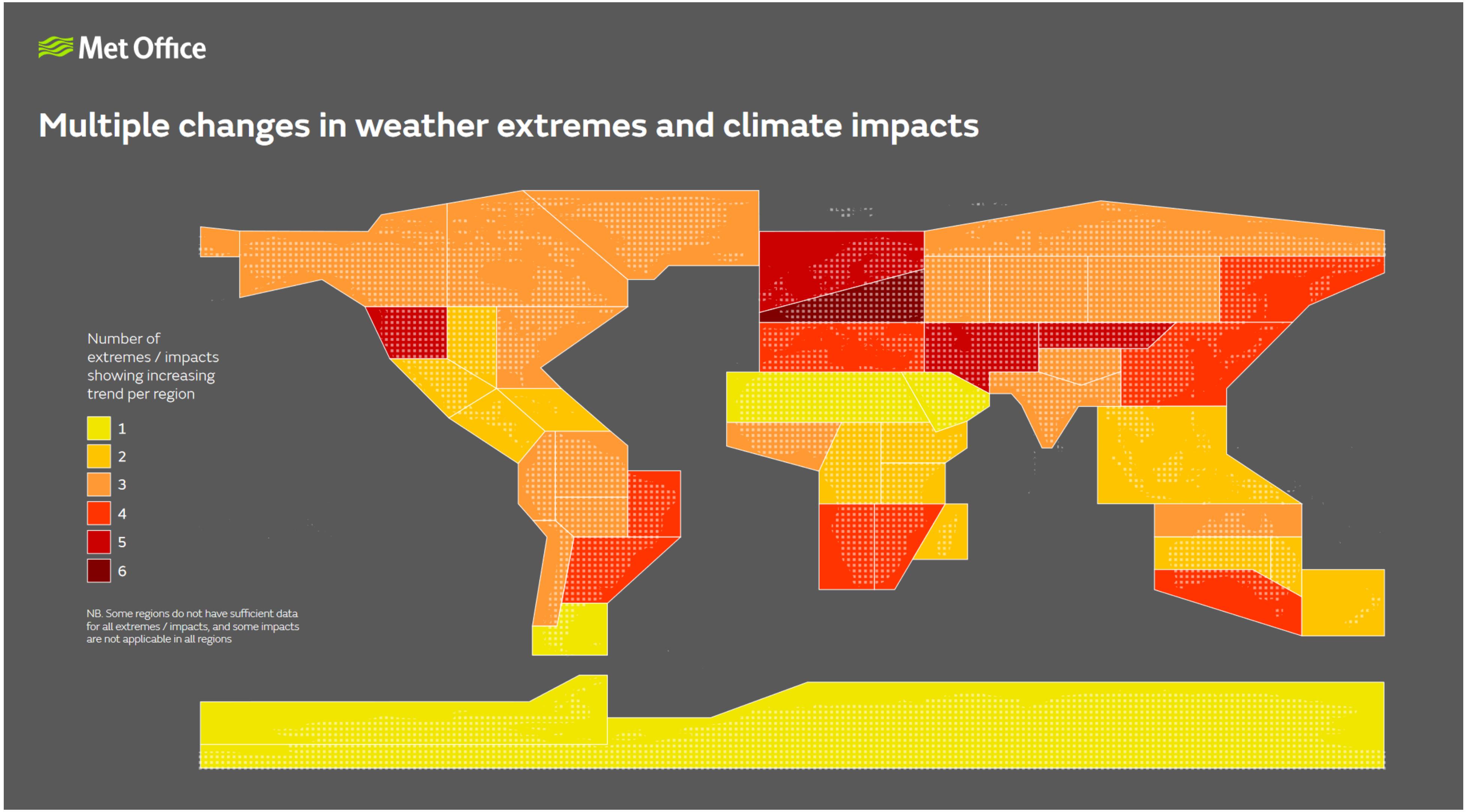


the likelihood of severe alterations in the normal functioning of a community or society due to weather or climate events interacting with vulnerable social conditions

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

Multiple extremes



The six categories covered in the study are:

- Extreme high temperatures
- Heavy rainfall
- River flows
- Agricultural drought
- Fire weather
- Loss of ice mass from glaciers

For further indepth reading please see:
Global hotspots for the occurrence of compound events

https://www.nature.com/articles/s41467-020-19639-3

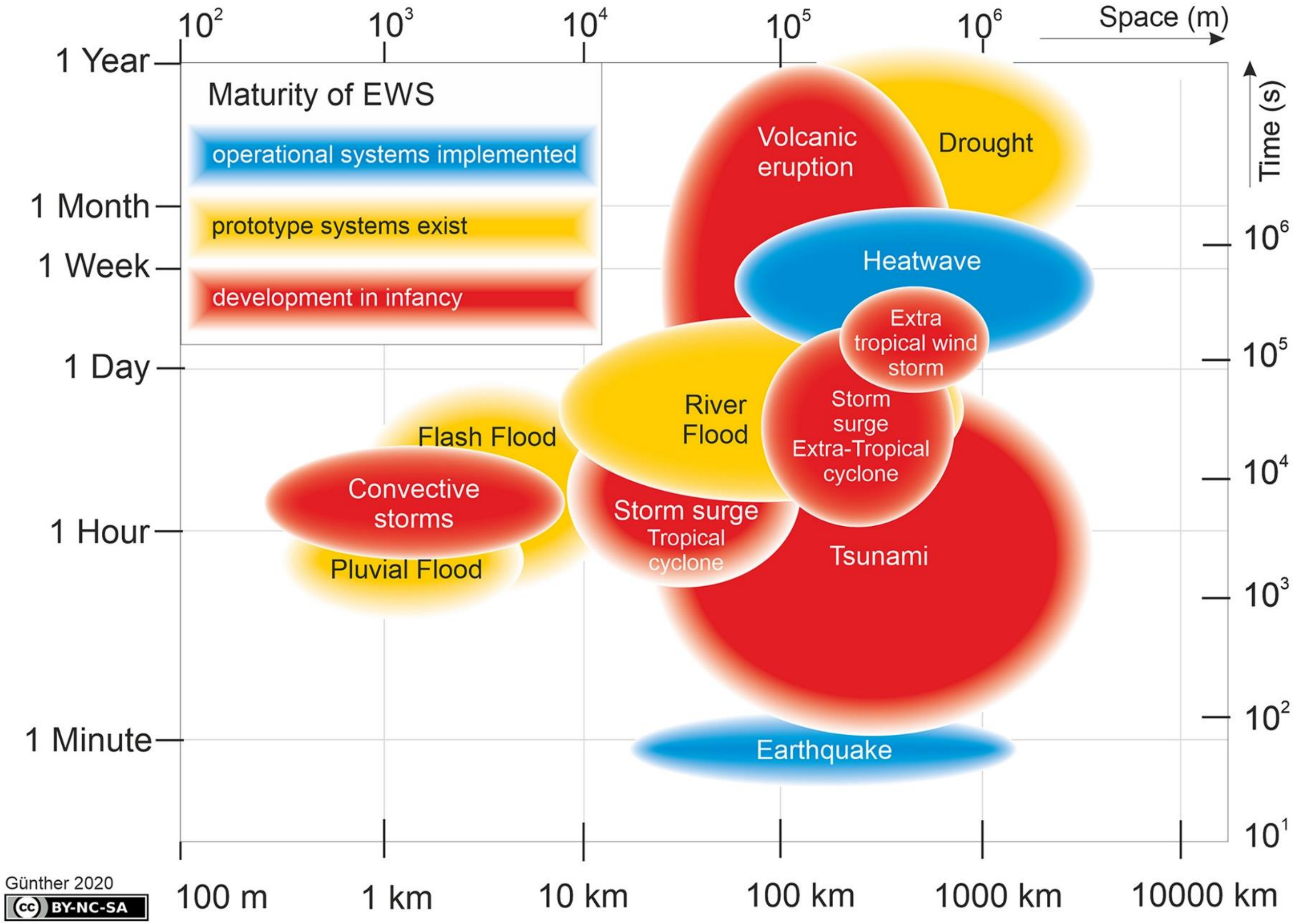
- https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2022/changes-in-weather-extremes-and-climate-impacts-from-the-poles-to-the-tropics

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

COP29 discussion