Science of Climate Change

Exercise session #9

Today's plan

- **Understand key concepts of climate extremes, how they are expressed and how they will evolve in a changing climate**
- **Understand key concepts of extreme value theory and extreme event attribution**

1. Multiple choice quiz: recap of lecture
2. Extreme value theory
   - Methods: Block maxima vs peak over threshold
   - Distributions
   - Conversion to return periods
3. Extreme event attribution
4. Time to work on assignments, poster etc

Lecture recap quiz

Instructions

Go to

www.menti.com

Enter the code

5726 3645

Or use QR code

Quiz solutions

Which of the following is NOT an extreme event associated to climate change?

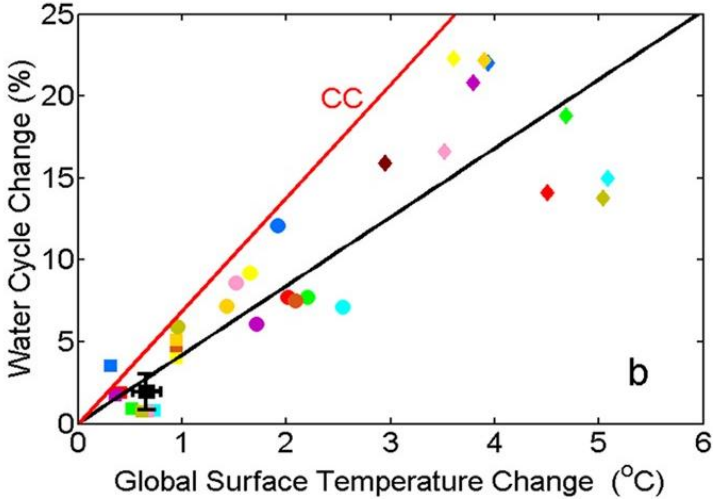
- Heatwaves
- Cold spells
- Heavy precipitation
- Tsunamis

Quiz solutions

Which physical process explains heavier precipitation in a warmer climate?

- The Clausius-Clapeyron relation
- A more pronounced environmental lapse rate
- Because of droughts, the water cycle is balanced by heavier precipitation
- Because the O-18 isotope is more present in clouds in a warmer climate

The Clausius-Clapeyron relationship predicts an increase in the water holding capacity of air (the saturation water vapor pressure) of approximately 7% per degree Celsius rise in temperature.



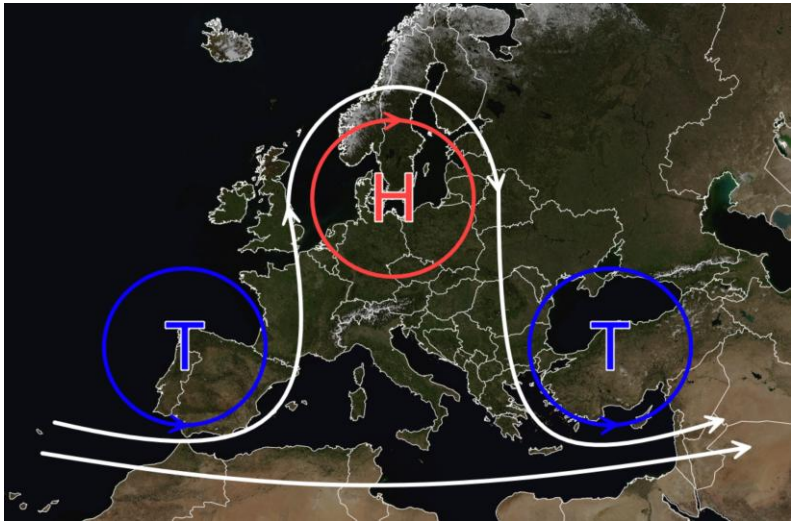
Skliris et al., 2016

Quiz solutions

What could be the reason of a heat wave over Europe?

- A displacement of the Hadley cell generate more subsidence over Europe
- A positive NAO index favours hot and dry weather over Europe
- A blocking anticyclone favours subsidence and clear sky for extended periods
- Stronger greenhouse effect generates extreme surface temperatures

Blocking anticyclones can lead to persistent weather conditions in the same location, such as hot and dry weather in summer



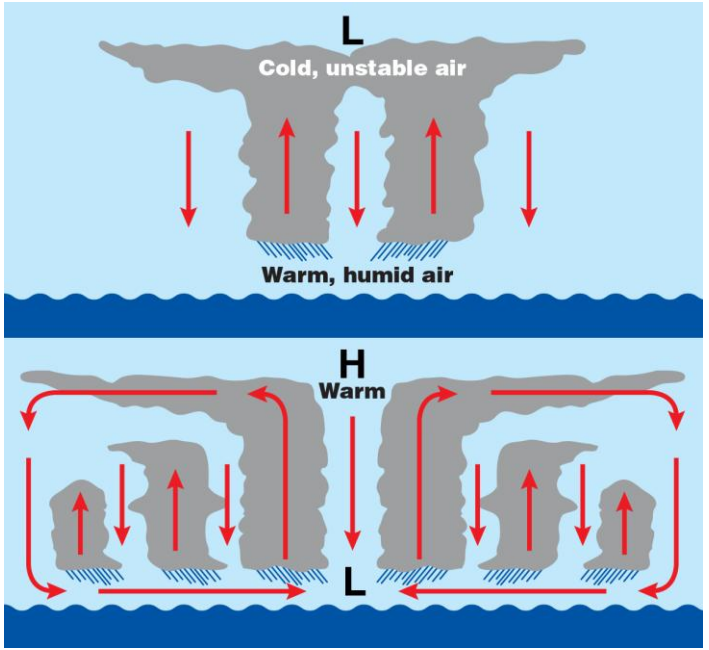
Meteoschweiz

Quiz solutions

Which proposition about tropical cyclones is true?

- More stronger (Cat. 4 or 5) cyclones per season because of warmer ocean
- The number of tropical cyclones per season is increasing
- No change in intensity and frequency
- Increased lifetime of cyclones

Hurricanes get their energy from warm surface water. With increased ocean temperature, they become stronger.



https://scijinks.gov/hurricane/

Quiz solutions

Increased weather extremes are due to

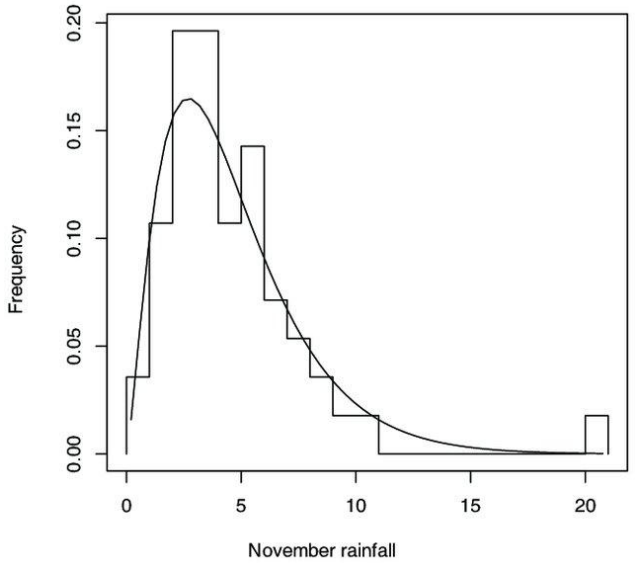
- more energy available in the atmosphere (thermodynamics)
- changed atmospheric circulation patterns (dynamics)
- Natural variability
- 1 & 2 are both correct

Quiz solutions

The daily precipitation probability density function follows a

- Fréchet distribution
- Weibull distribution
- Gumbel distribution
- Gamma distribution

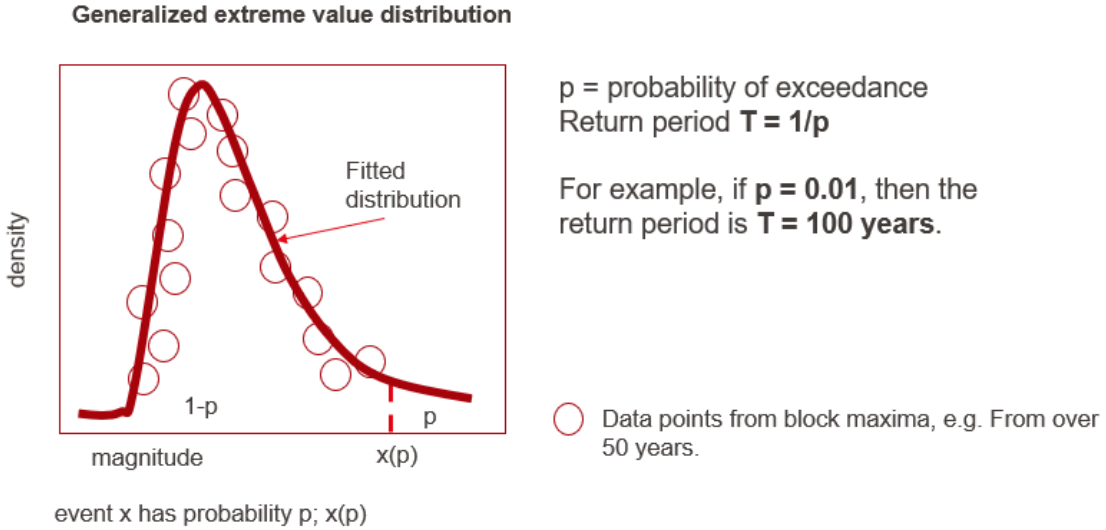
The gamma distribution typically describes best mean precipitation. Weibull, Fréchet and Gumbel are extreme value distributions and are therefore only valid for maxima.



Quiz solutions

The probability of a 200-year event to occur on a specific year is:

- 2 %
- 0.5 %
- it depends on the shape parameter of the GEV distribution
- It depends when such an event happened for the last time

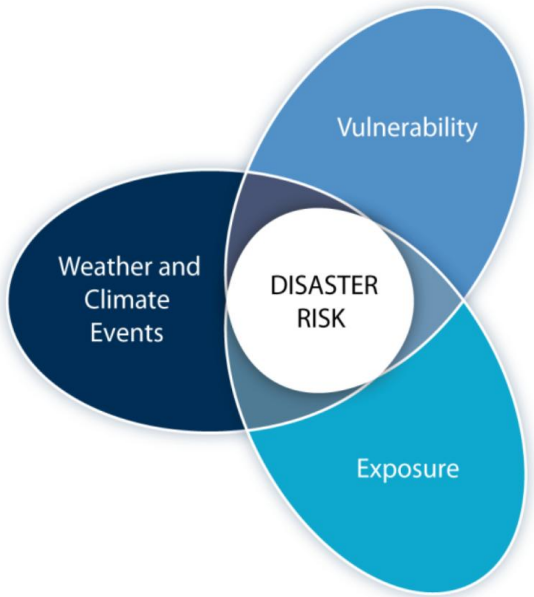


T = 1/200 = 0.005 = 0.5 %

Quiz solutions

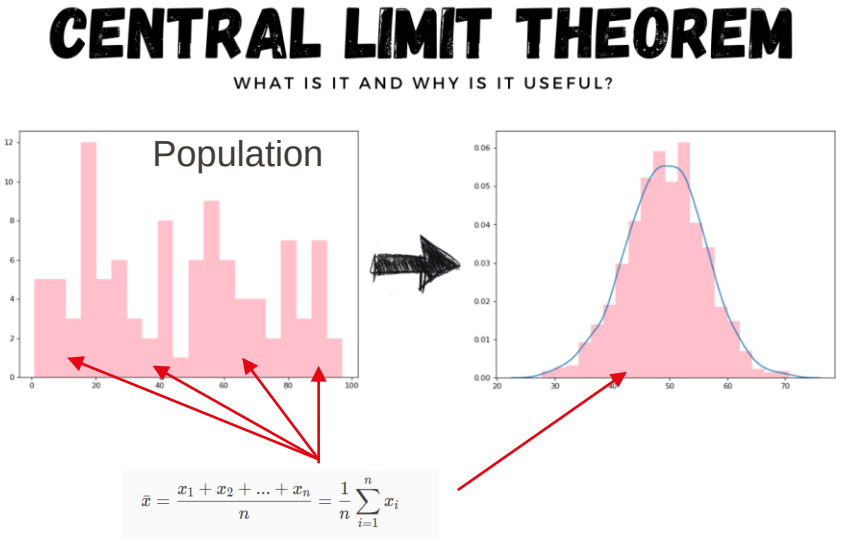
What parameters are taken into account to define the likelihood of severe alteration to functioning of a society?

- Weather and climate events, Exposure, Implemented adaptation strategies
- Exposure, Economic development, Historical occurence of extremes
- Weather and climate events, Exposure, Potential economical loss
- Weather and climate events, Exposure, Vulnerability



Extreme value theory recap

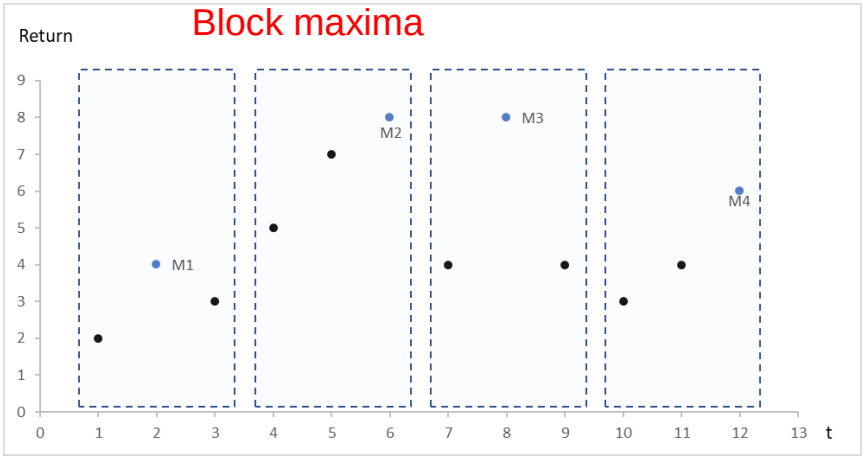
- Similar to Central Limit Theorem but for maxima instead of mean

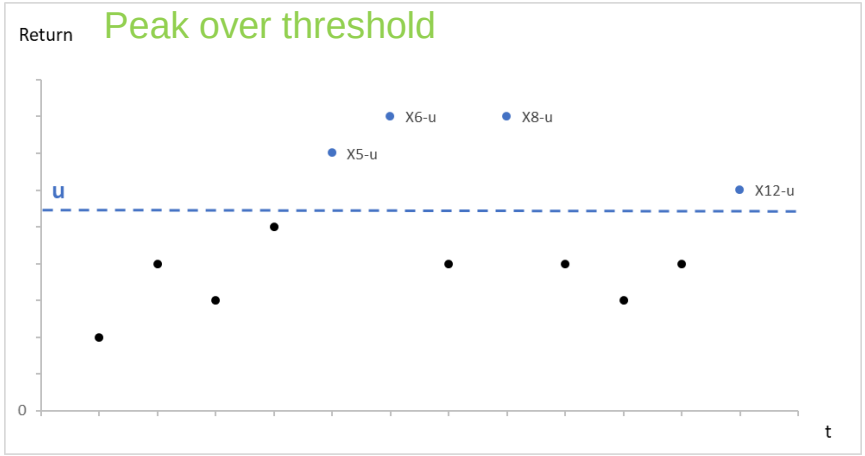


Central limit theorem states that if you take repeated samples from a population and compute their mean, the means are normally distributed, no matter what the population distribution look like

Extreme value theory recap

- Now, instead of using sample means, we use maxima.
- But how do we define maxima?
- 2 methods:





Block Maximum

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

for $n \to \infty$

M_n follows a **Generalized Extreme Value (GEV)** distribution

What are inconveniences or considerations to take into account for each method?

Peak over Threshold (POT)

$\{X_i - u | X_i > u\}$

very large threshold u

follow a **Generalized Pareto Distribution (GPD)**

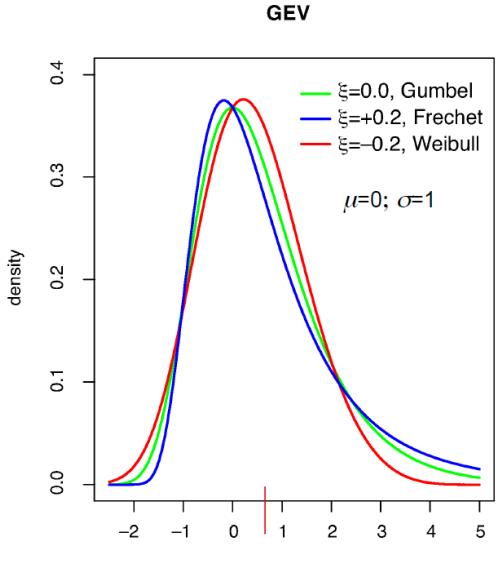
Extreme value theory recap

- **The GEV Distribution (CDF)**

$$GEV(x;\mu,\sigma,\xi) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

$$\text{where}: \quad 1+\xi\cdot\frac{x-\mu}{\sigma} > 0$$

  - A combined parametrisation of all three limit distributions
  - Three parameters: Location (μ), Scale (σ), Shape (ξ)
  - $\xi = 0$: Gumbel, unbounded
    $\xi > 0$: Fréchet, lower bound
    $\xi < 0$: Weibull, upper bound



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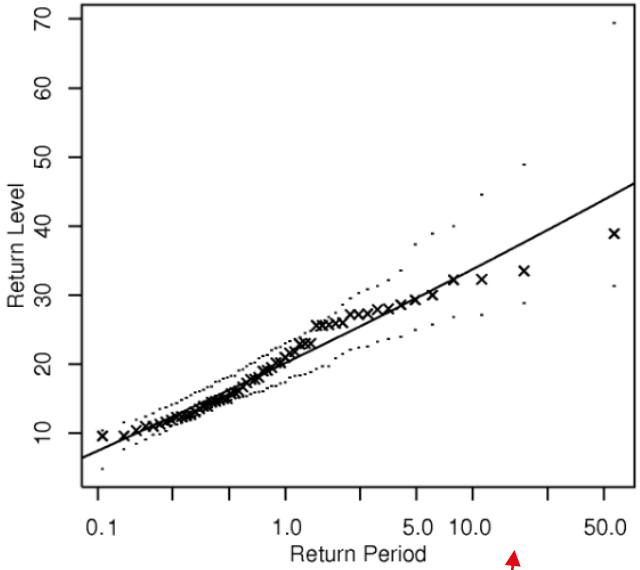


p = probability of exceedance
Return period **T = 1/p**

→ based on the probability of exceedance of a given value, we can convert the GEV distribution into a return period graph

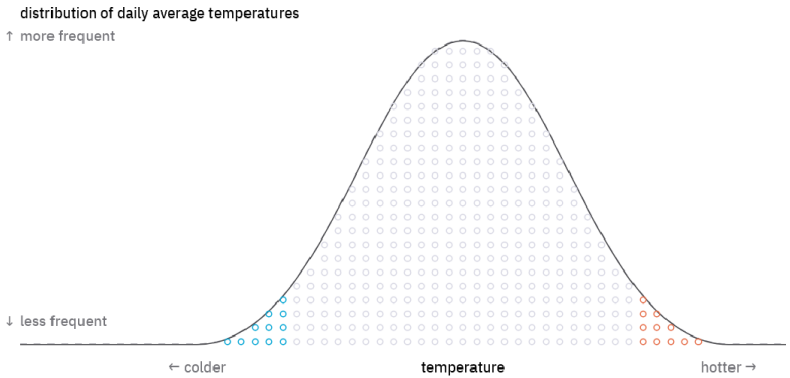
Can be extrapolated to events with return periods larger than the data record period

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

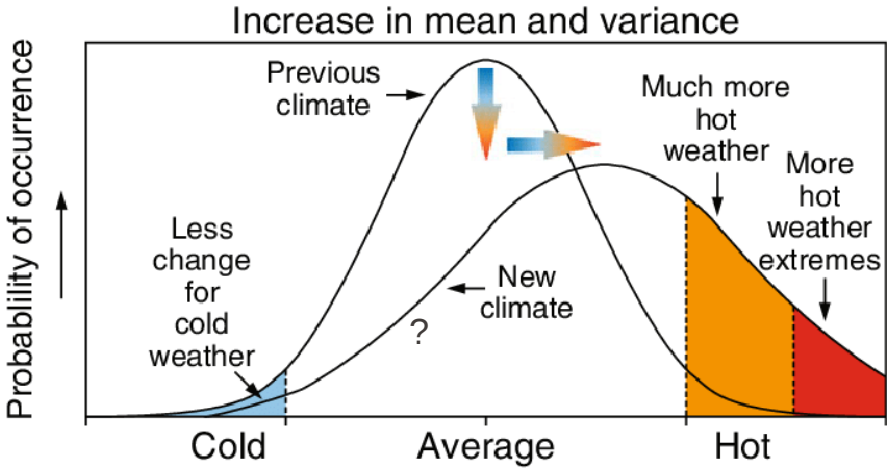
Extreme value theory recap

How will extremes evolve with climate hange?

Current climate



Future climate



Extreme event attribution

- Quantification of climate change contribution to some types of extreme events is possible

World Weather Attribution

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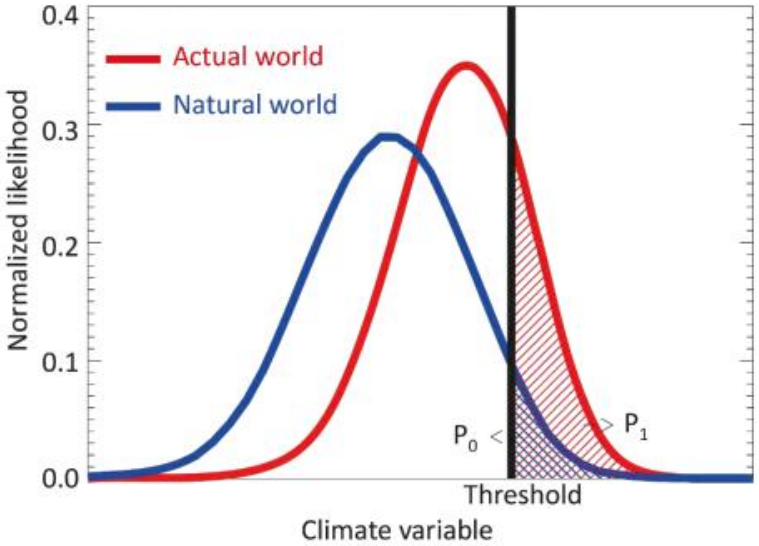
Extreme downpours increasing in Southern Spain as fossil fuel emissions heat the climate

- World Weather Attribution – Exploring the contribution of climate change to extreme weather events

Probability-based approach

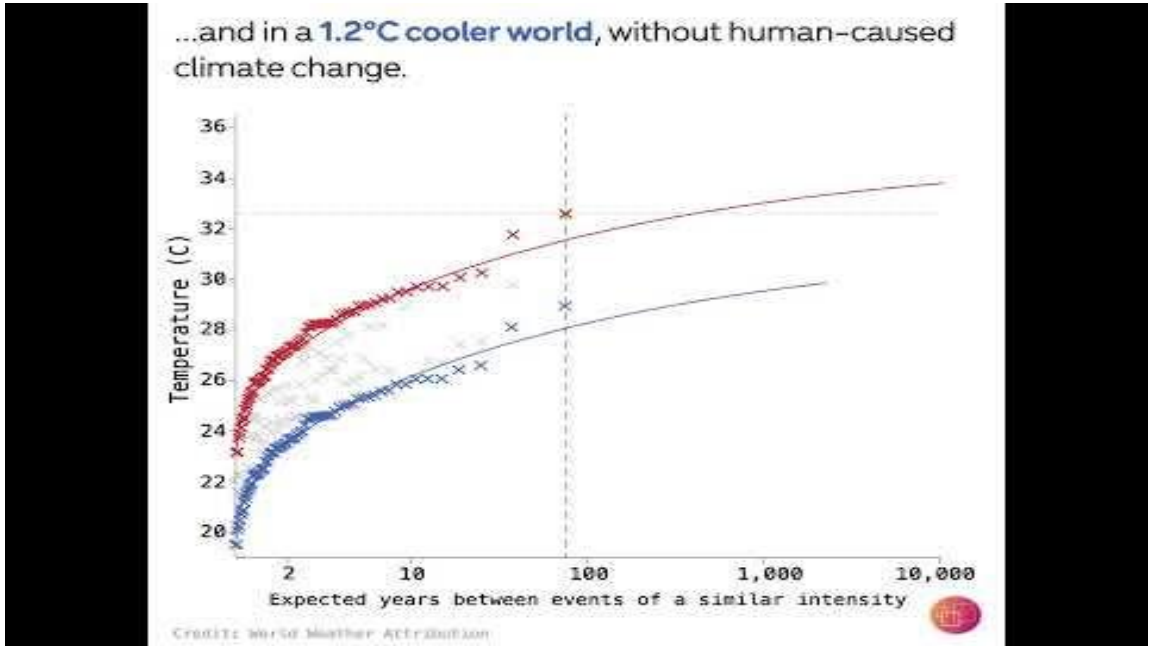
- Many methods developed
- One method is the probability-based approach
  - p_1: probability of event in present-day climate, the "factual"
  - p_0: probability of event in past climate, the "counterfactual"
  - Probability ratio: **PR = p_1 / p_0**
  - Fraction of Attributable risk: **FAR=1 – p_0 / p_1**



Based on a presentation by Fischer and Fröhlicher, SCSS 2024

8-step procedure

1. Analysis trigger
2. Event definition
3. Observational trend analysis
4. Climate model evaluation
5. Climate model analysis
6. Hazard synthesis
7. Analysis of trends in vulnerability and exposure
8. Communication



https://www.worldweatherattribution.org/methods/

Philip et al. 2020, Oldenborgh et al. 2021

Take home message

- With climate change, extremes will be more frequent, more intense and of longer duration
- Extreme events have impact in all regions of the planet
- Implications are: Economical losses, population migration, social impacts, casualties…
- Extreme value theory can be applied to data records to predict the probability of an event of a certain magnitude
- Extreme event attribution is used to estimate how climate change influenced the likelihood and intensity of the weather event