Koninklijk Nederlands
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Ministerie van Infrastructuur en Milieu

Extremes in climate science

31.01.2012

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With material from Albert Klein Tank (KNMI)

- Why extremes?
- Moderate extremes
- “Real” extremes
- Modelling extremes
- Changing extremes
- Research questions

Climate and the climate system

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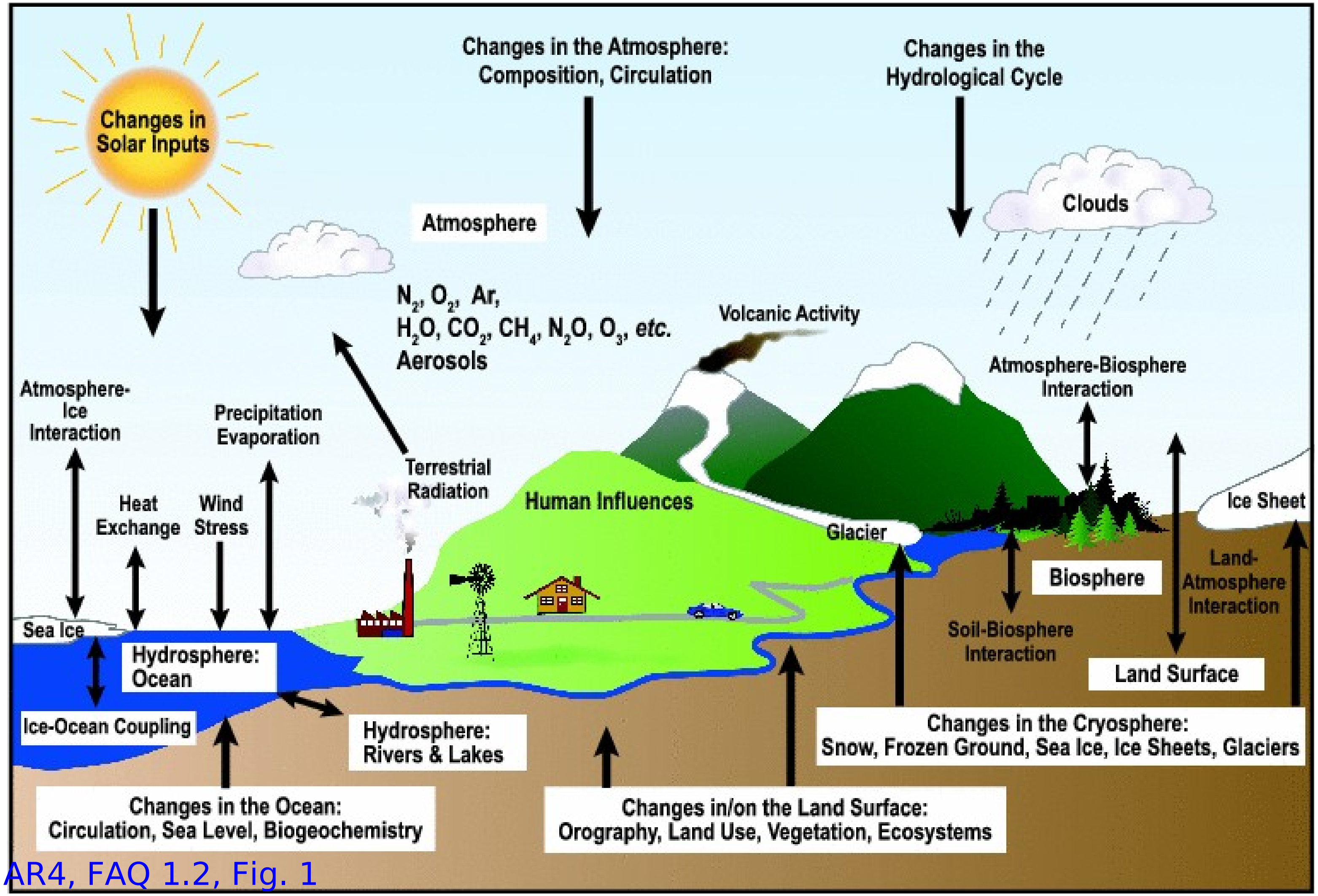
Climate – what's that?

Climate = statistics of weather

Weather = state of atmosphere at a particular time

"Climate is what you expect, weather is what you get"

The climate system



AR4, FAQ 1.2, Fig. 1

Chaotic system

- Multitude of physical, chemical and biological processes interacting
- Length scales from millimetres to 1000 km
- Time scales from seconds to centuries (and beyond)
- External (non-deterministic) influences: sun, volcanoes, anthropogenic effects (GHG emissions)

=> deterministic forecast limited to ~10 days (weather)

=> only statistics beyond (climate)

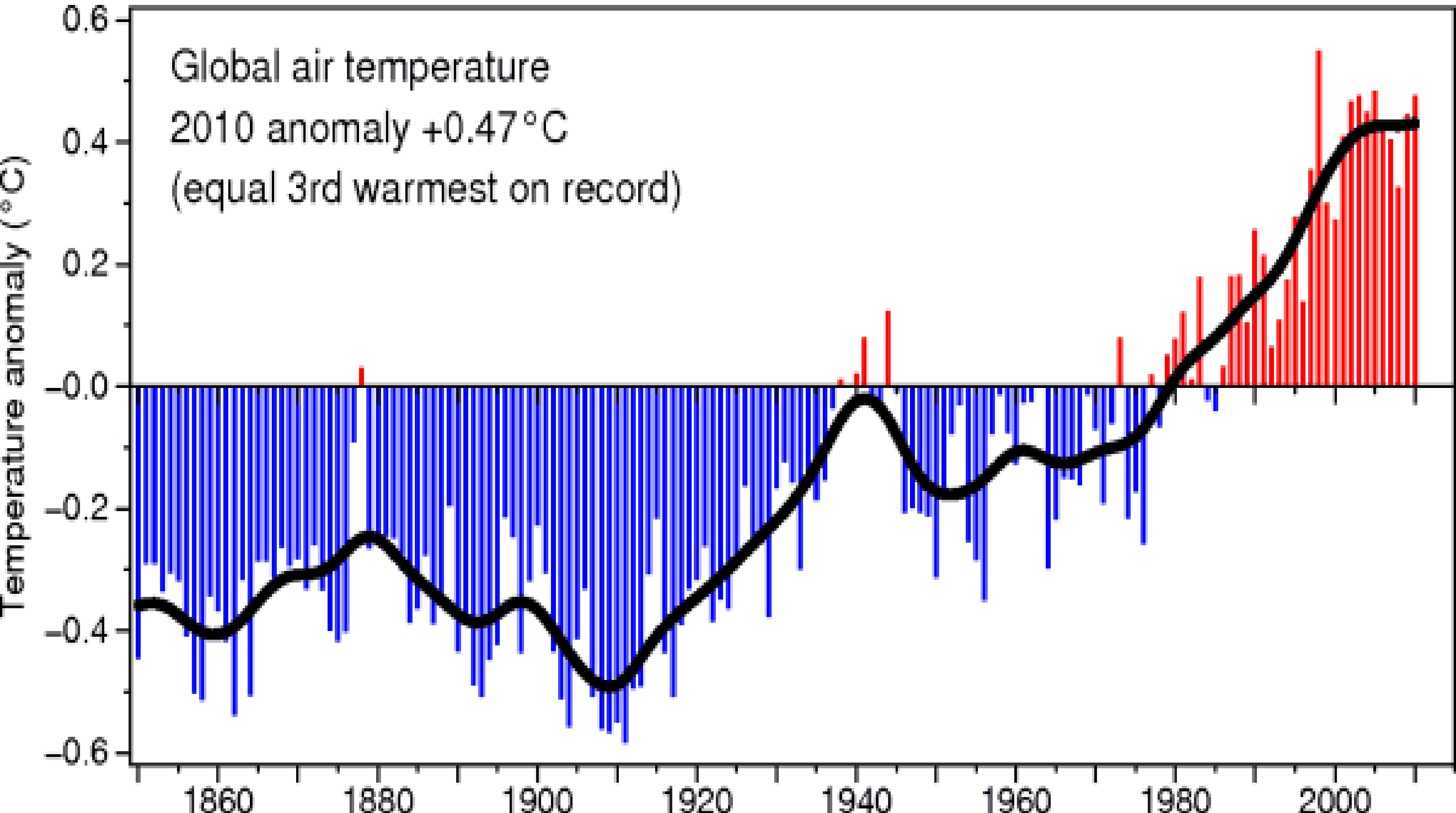
Climate change

GHG concentrations increase

=> Temperature increases
=> other weather elements (wind, precip, clouds) change

Question: How do their statistical properties (esp. extremes) change?

The past 161 years



Extremes

Extremes

High impact (vulnerability)

Rare events (tentatively: once per >10 years)

- May not have occurred in known history -> Extrapolation
- Extreme value theory (EVT)

Moderate (soft) extremes (tentatively: once per year; simple, robust)
Climate indices, e.g.

- TX90p: warm days (= number of days with T > 90%-ile)
- RX5D: monthly maximum of consecutive 5-day precipitation

Wide range of space and time scales:
From very small scale (tornadoes) to large scale (drought)

Change of extremes under climate change

Vulnerability

Societies / ecosystems / infrastructures are well-adapted to their mean climate, including “moderate” variability, ...

... but vulnerable to extremes ($p < 10^{-1}$/y) due to exceeded thresholds

Mean climate change is small compared to natural variability, but ...

... thresholds will be exceeded more often

Question: How often?

Analysis of extremes

Rare events:

Requires long and homogeneous time series

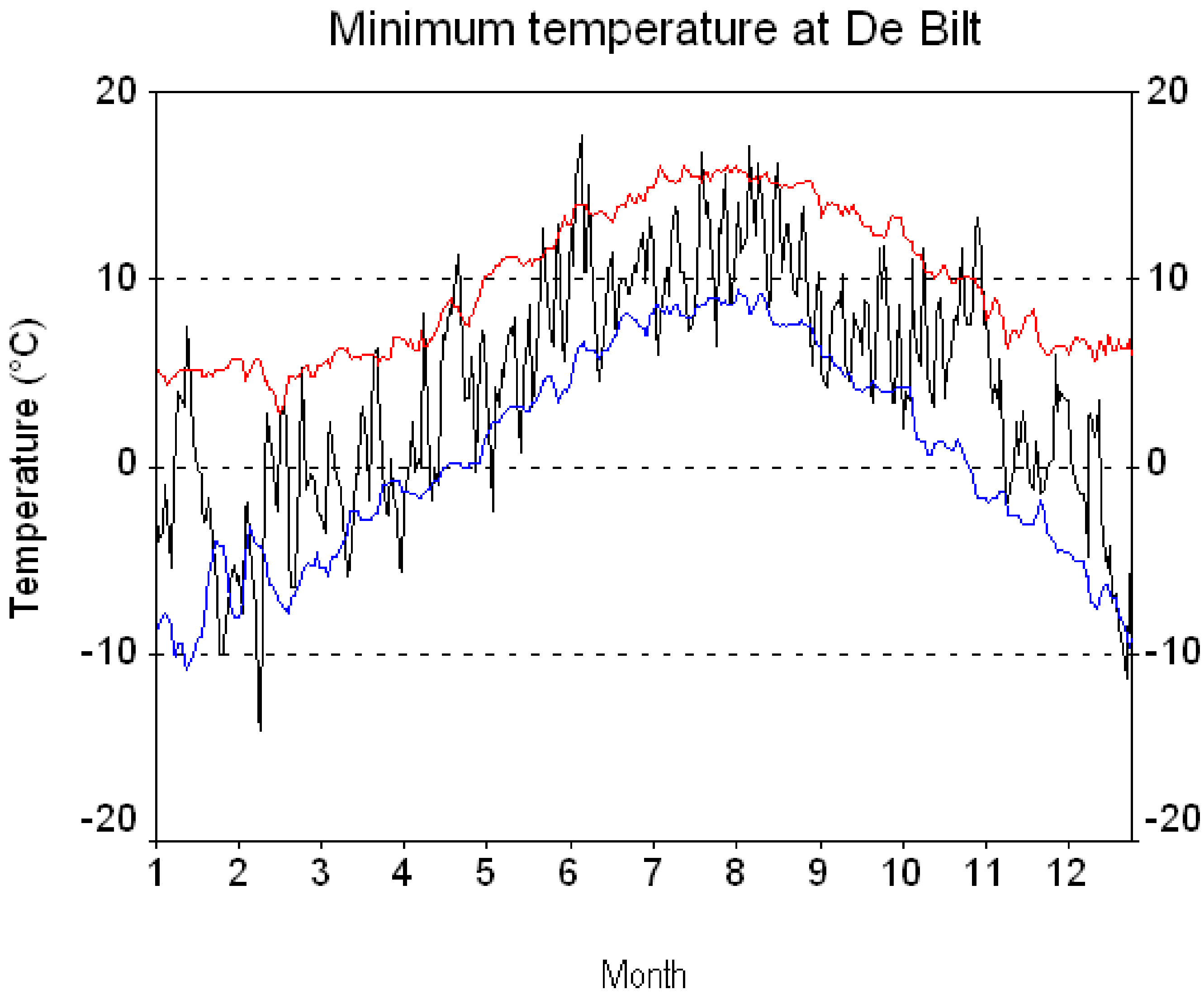
Often not available in obs

=> moderate extremes

Analysis of extremes

- For analyzing moderate extremes an internationally coordinated set of descriptive indices can be used, which describe frequency, amplitude, persistence
- User-friendly R-based software (RClimDex) for their calculation is available from http://cccma.seos.uvic.ca/ETCCDI
- cdo software (https://code.zmaw.de/projects/cdo) can also calculate them
- One key approach involves counting the number of days in a season or a year that exceed specific thresholds

Analysis of extremes

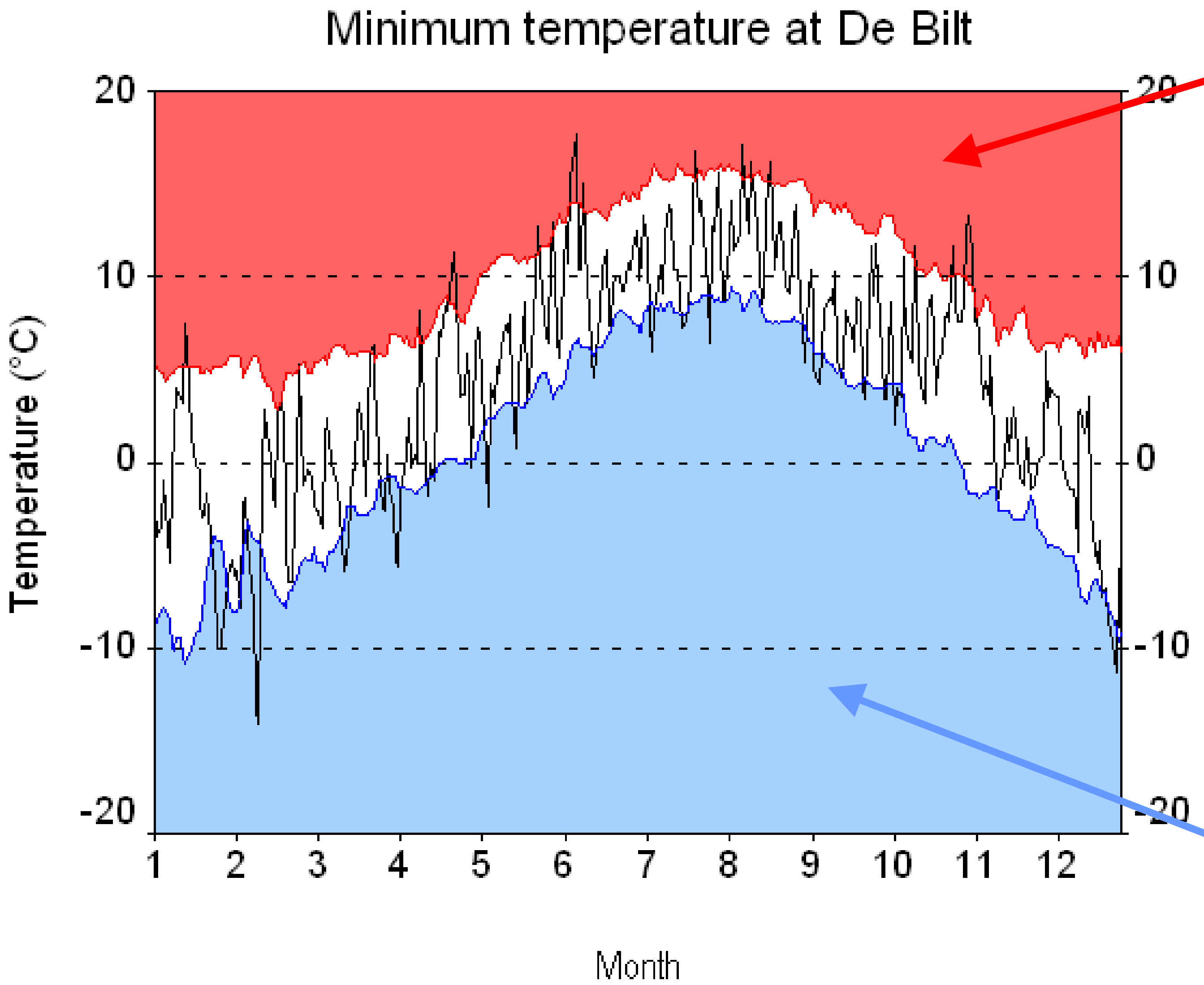


upper 10%-ile
1961-1990

the year 1996

lower 10%-ile
1961-1990

Analysis of extremes



"warm nights"

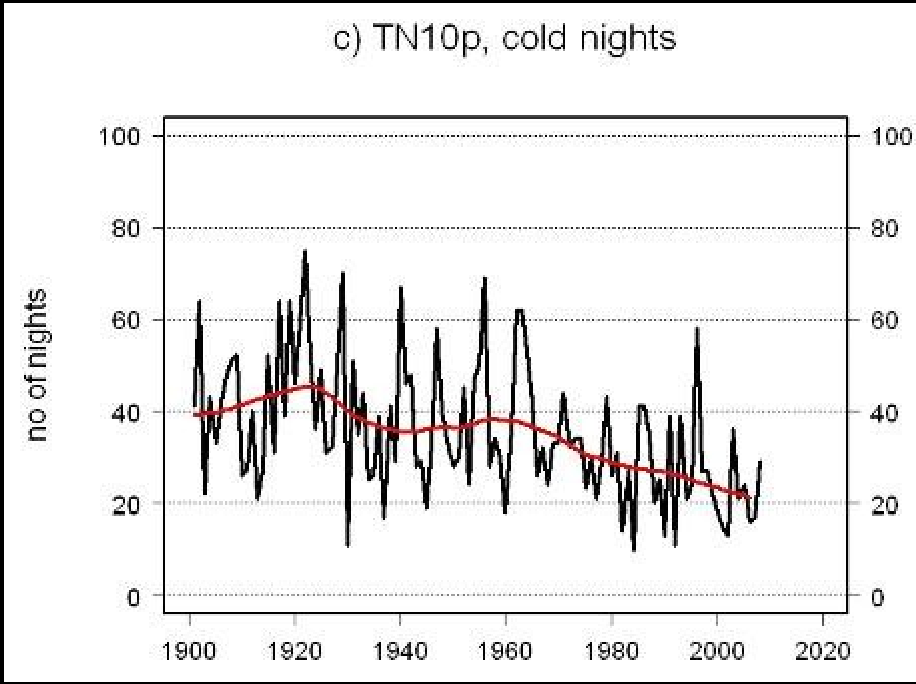
upper 10%-ile 1961-1990

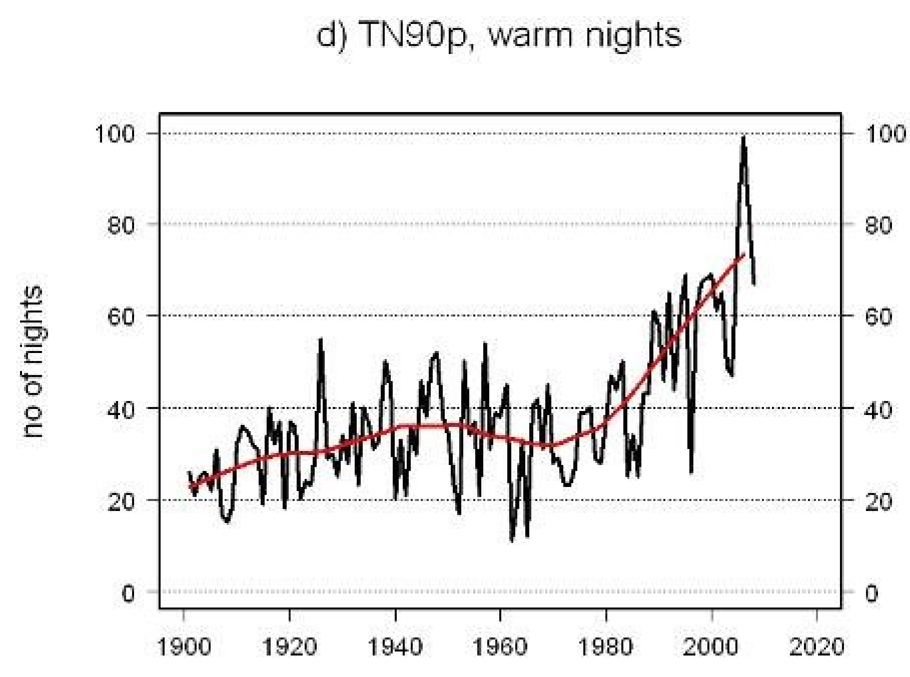
the year 1996

lower 10%-ile 1961-1990

"cold nights"

Analysis of extremes

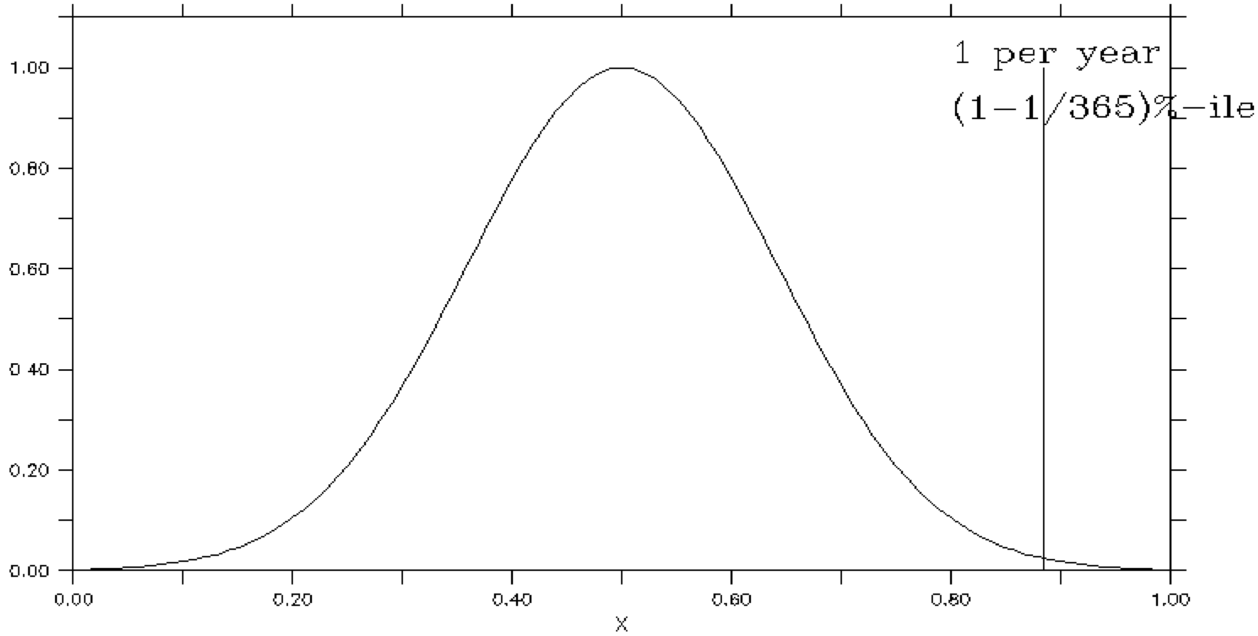




De Bilt, the Netherlands

EVT - 1

Extremes: tail of a distribution
=> few observations
=> tail badly constrained



EVT - 2

Fortunately, the tails of distributions behave similarly.
They are described by Extreme Value Theory.

Two basic approaches:
1. Block-maxima (=> GEV)
2. Peak-over-Threshold (POT; => GPD)

GEV

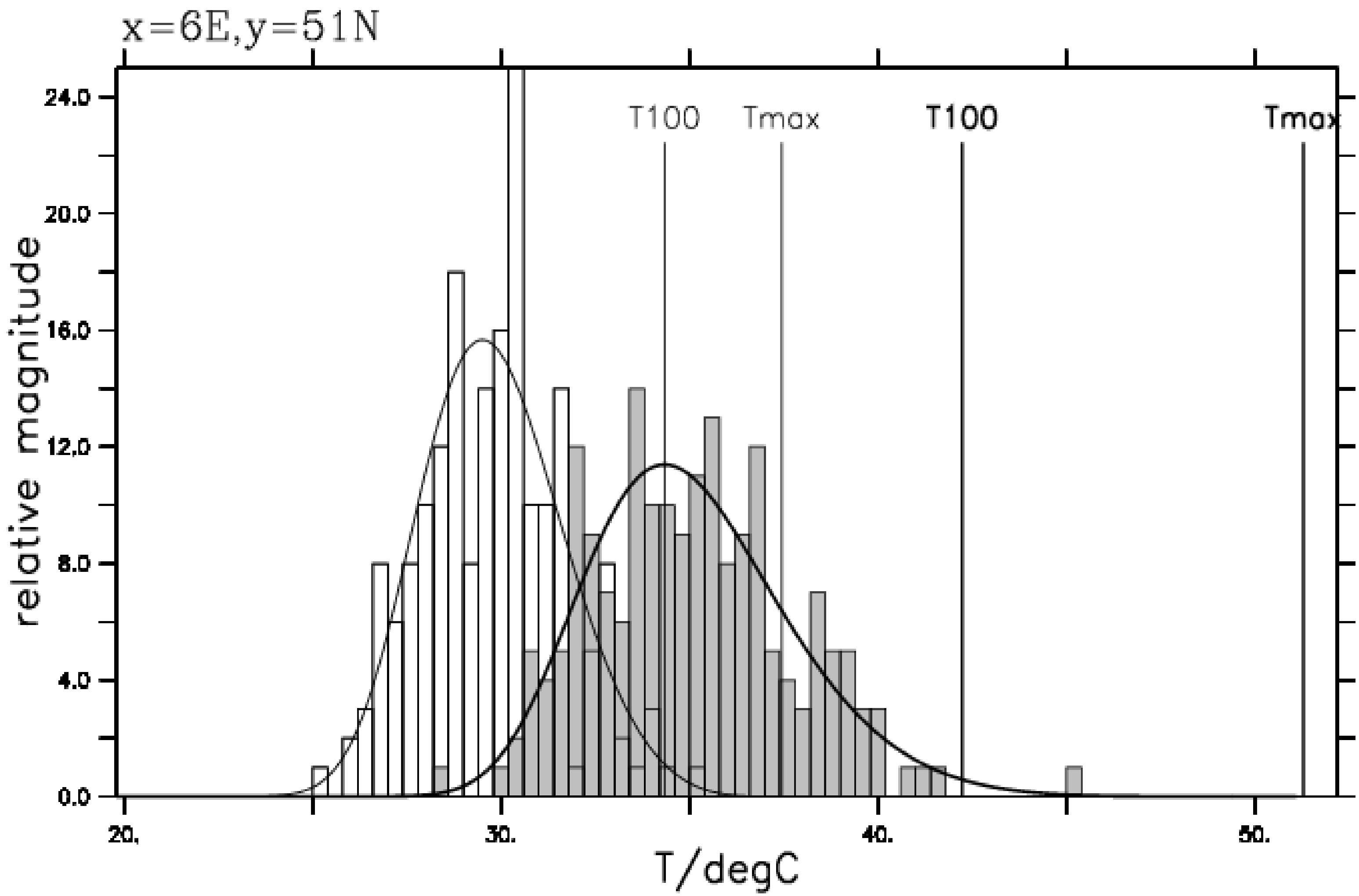
Under very general conditions the distribution of block-maxima is given by the GEV distribution

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

$$1+\xi\left(\frac{x-\mu}{\sigma}\right) > 0$$

μ: location
σ: scale
ξ: shape

Example: Temperature in the Netherlands



Visualization: Gumbel plot

Plot as function of Gumbel variate

$$x = -\ln(-\ln(G(y)))$$

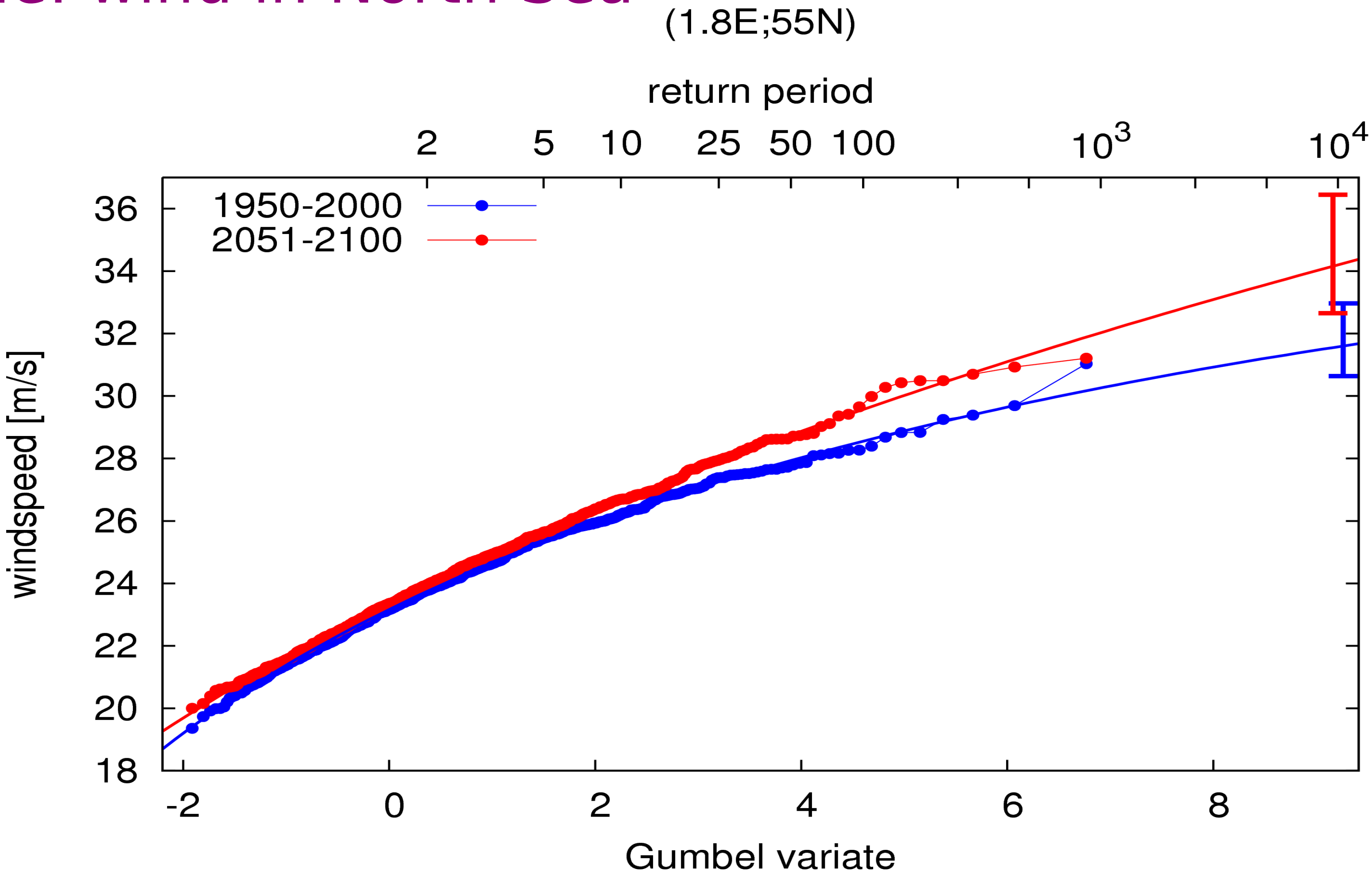
ξ = curvature; straight line for $\xi = 0$ (Gumbel distribution)

σ = slope

μ = value at $x = 0$

One-to-one relation with return time (average time between events)

Example: wind in North Sea



POT

Exceedences (x > u) follow Poisson process (i.e., intervals between them are Poisson-distributed)

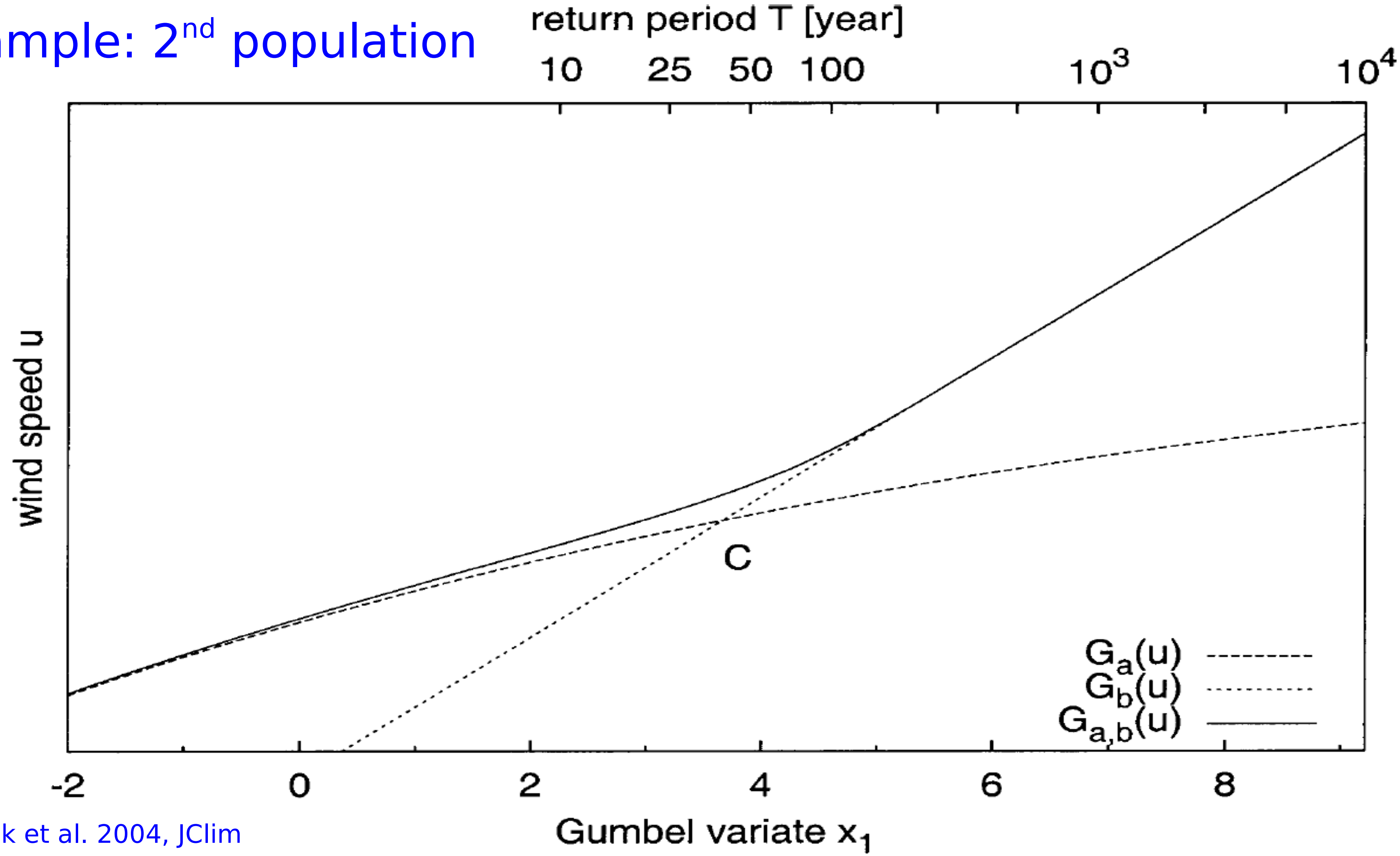
=> exceedences follow GPD:

$$F_u(x) = \begin{cases} 1 - (1 - \kappa x/\alpha)^{1/\kappa} & \text{if} \quad \kappa \neq 0 \\ 1 - \exp(-x/\alpha) & \text{if} \quad \kappa = 0, \end{cases}$$

Considerations

- Distribution => confidence interval
- Choice of block length (threshold)
  - Independent events (=> declustering)
  - Small => more data => greater confidence
  - Large => further out in tail => conditions better satisfied
- Tail must be determined by one type of process
  - You have to be far enough in the tail
  - Increasing block length (GEV) or threshold (GPD) should not change result
  - 2^{nd} population (large-scale *vs*. convective precip; cyclone *vs.* hurricane)
- Increased convergence if fitted to x^k, k = shape of parent distribution

Example: 2nd population



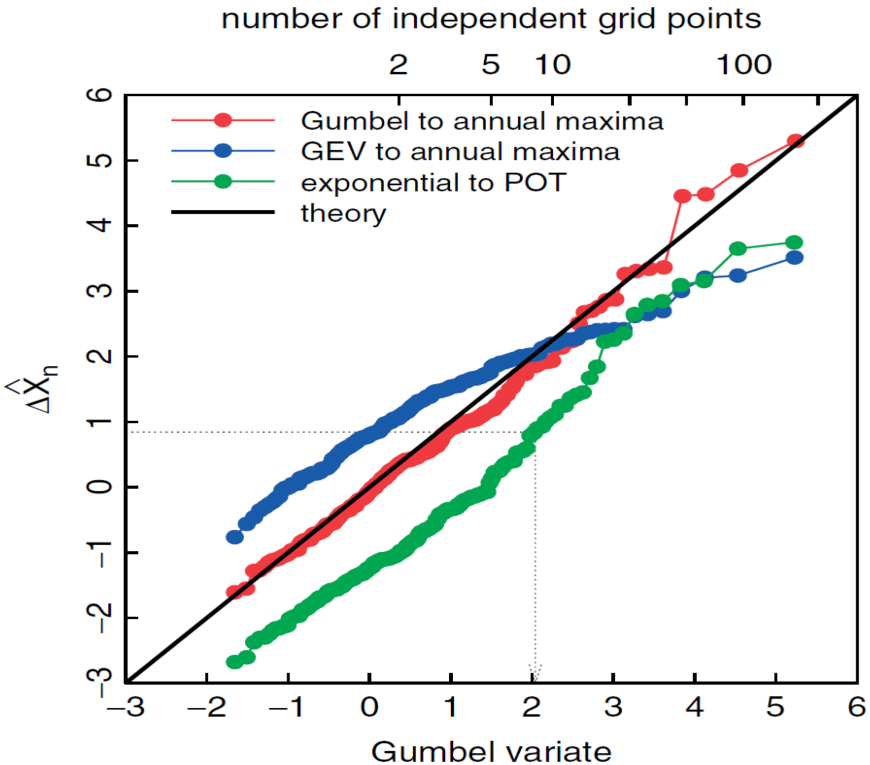
v/d Brink et al. 2004, JClim

Henk's method

Deviations of the highest event from fit are Gumble distributed.

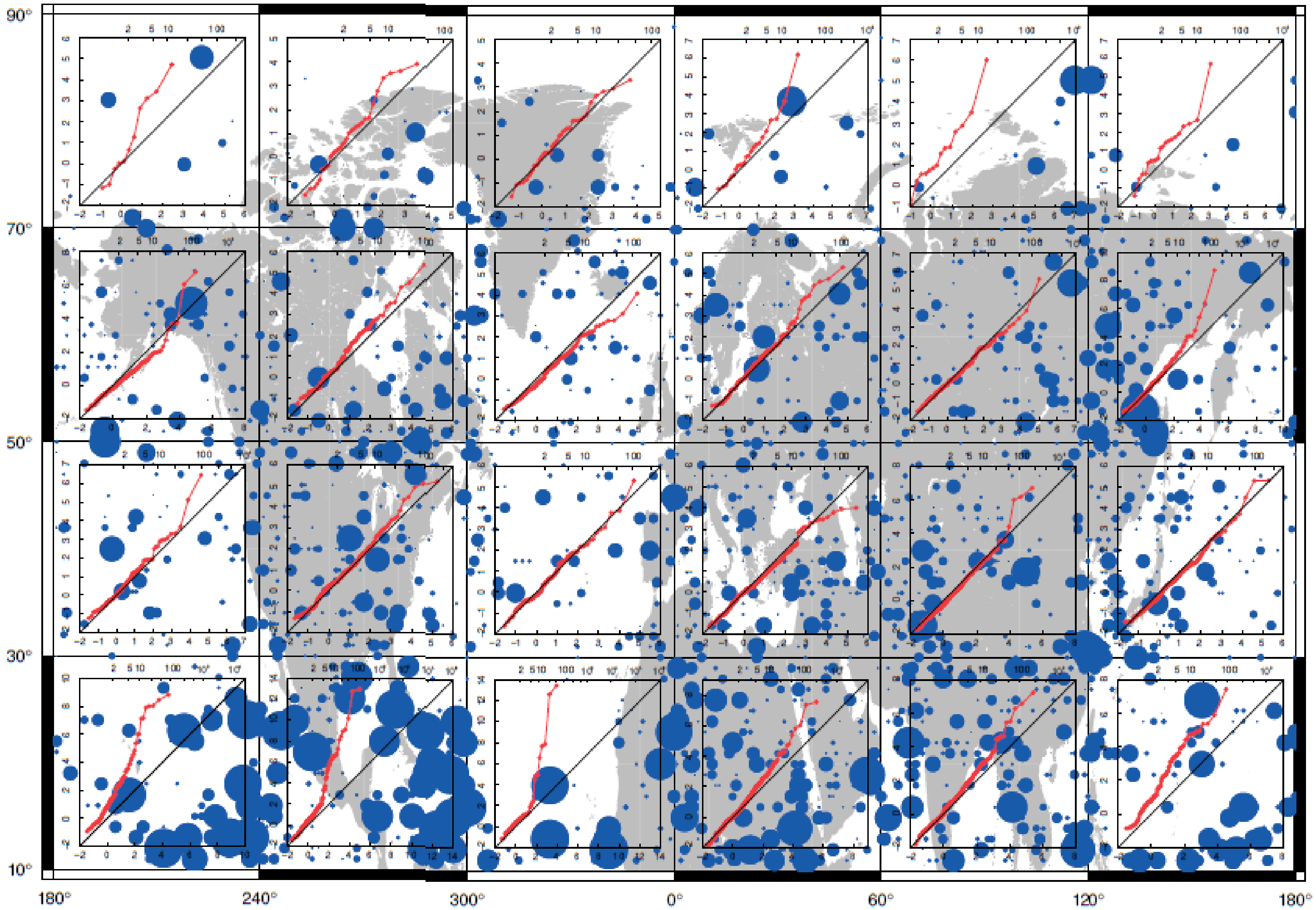
Examining a lot of fits, the appropriateness of the chosen distribution can be assessed.

Extreme wave heights (30-70°N) fitted to three different distributions. Deviations of highest events should be Gumbel-distributed.
=> Gumbel performs best.



v/d Brink, Können, 2009

Distributions of highest deviations of ERA-40 winds fitted to a Gumbel distribution. In the tropics a 2nd populations is visible.



v/d Brink, Können, 2009

Analysis of extremes

- Among others, a user-friendly R-based toolkit (extRemes) is available from

  http://www.assessment.ucar.edu/toolkit

  (Stephenson and Gilleland, 2006; Gilleland and Katz, 2005)

Example: waterlevels Dutch coast

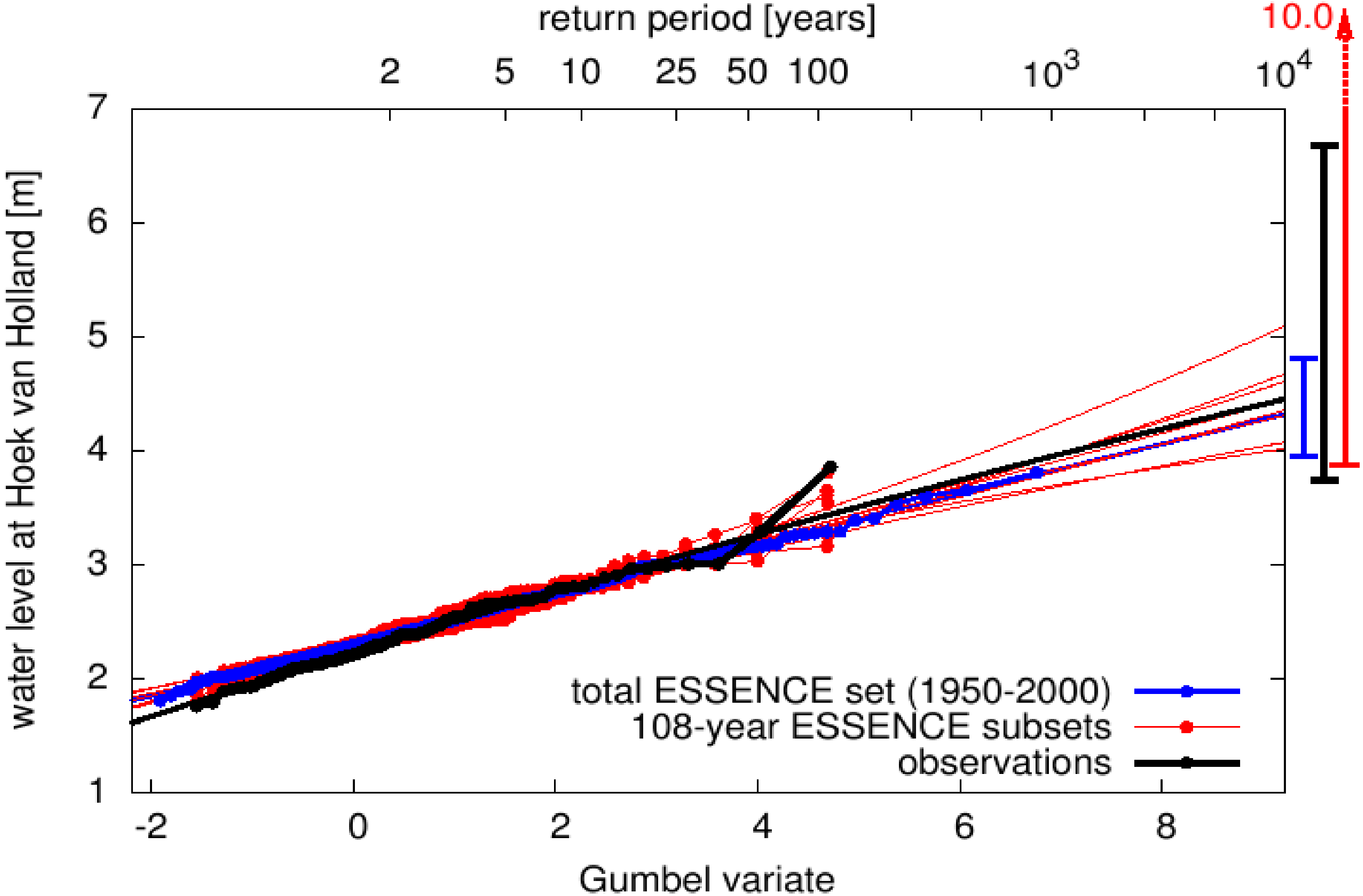
Essence

ECHAM5/MPI-OM
17-member ensemble
1950-2100, SRES A1b

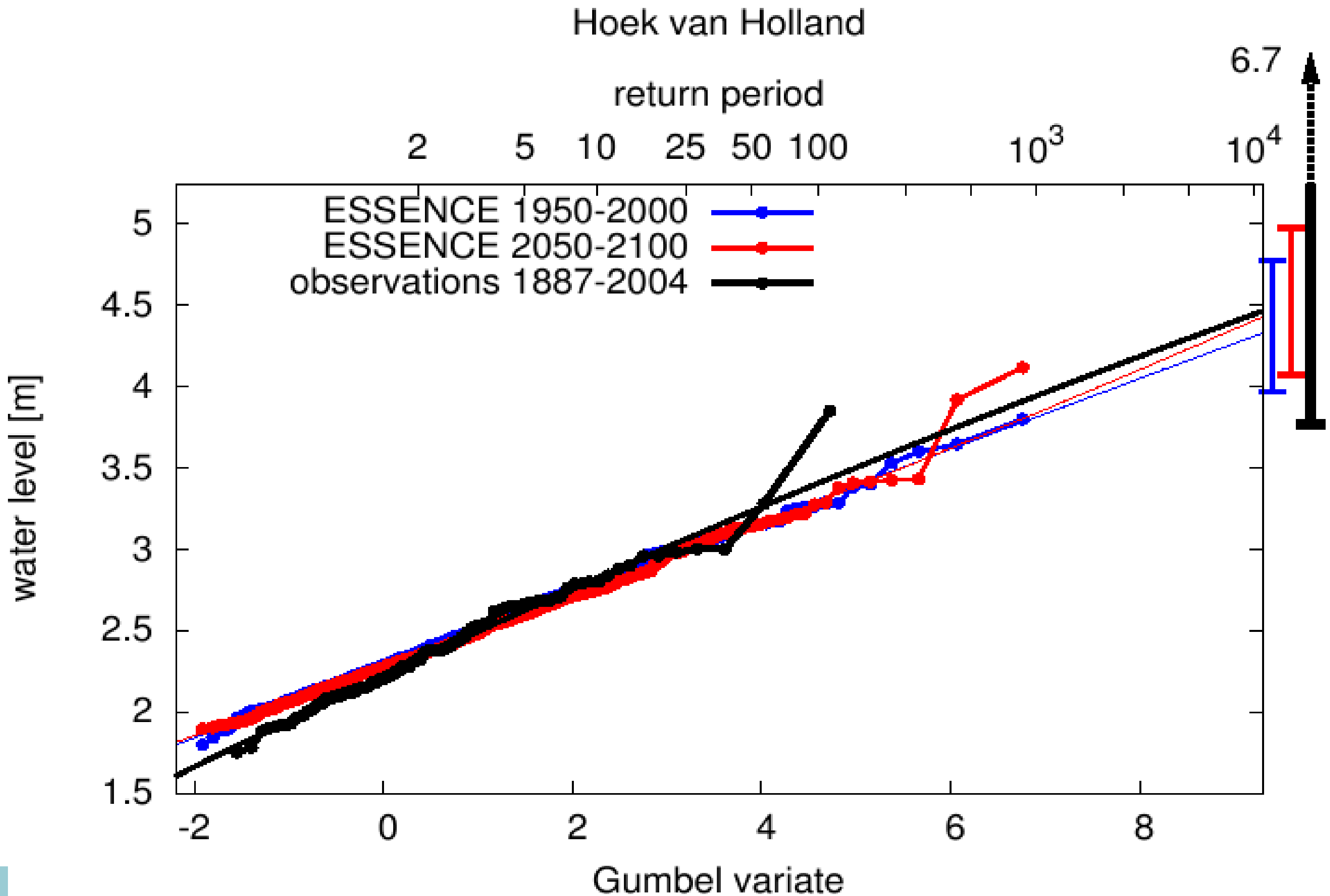
WAQUA

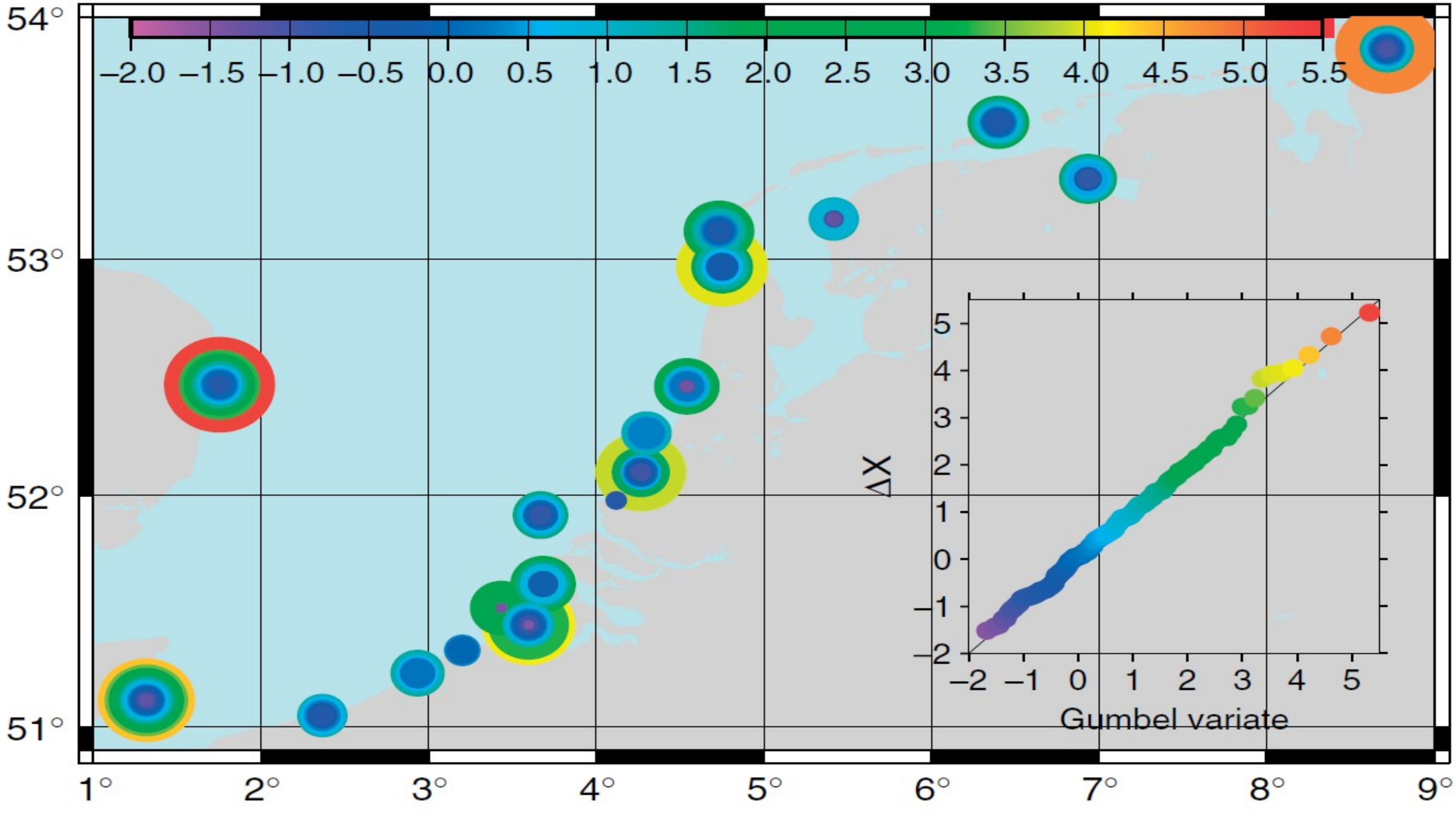
storm surge model
Northwest European shelf
8 km x 8 km
output every 10 minutes

Uncertainty present-day water levels



Future water levels





Deviations from a Gumbel-fit (GEV with shape nearly 0): same model can be used for all points

v/d Brink, Können, 2009

Research Questions

Co-variates, especially time

Make parameters (μ, σ) time dependent (linear, El Niño)

Attribution

Min et al. 11: change over time; fingerprint method

Poll et al. 11: one specific event; large ensemble

Physical modelling of extremes:

Under what conditions do extremes occur?

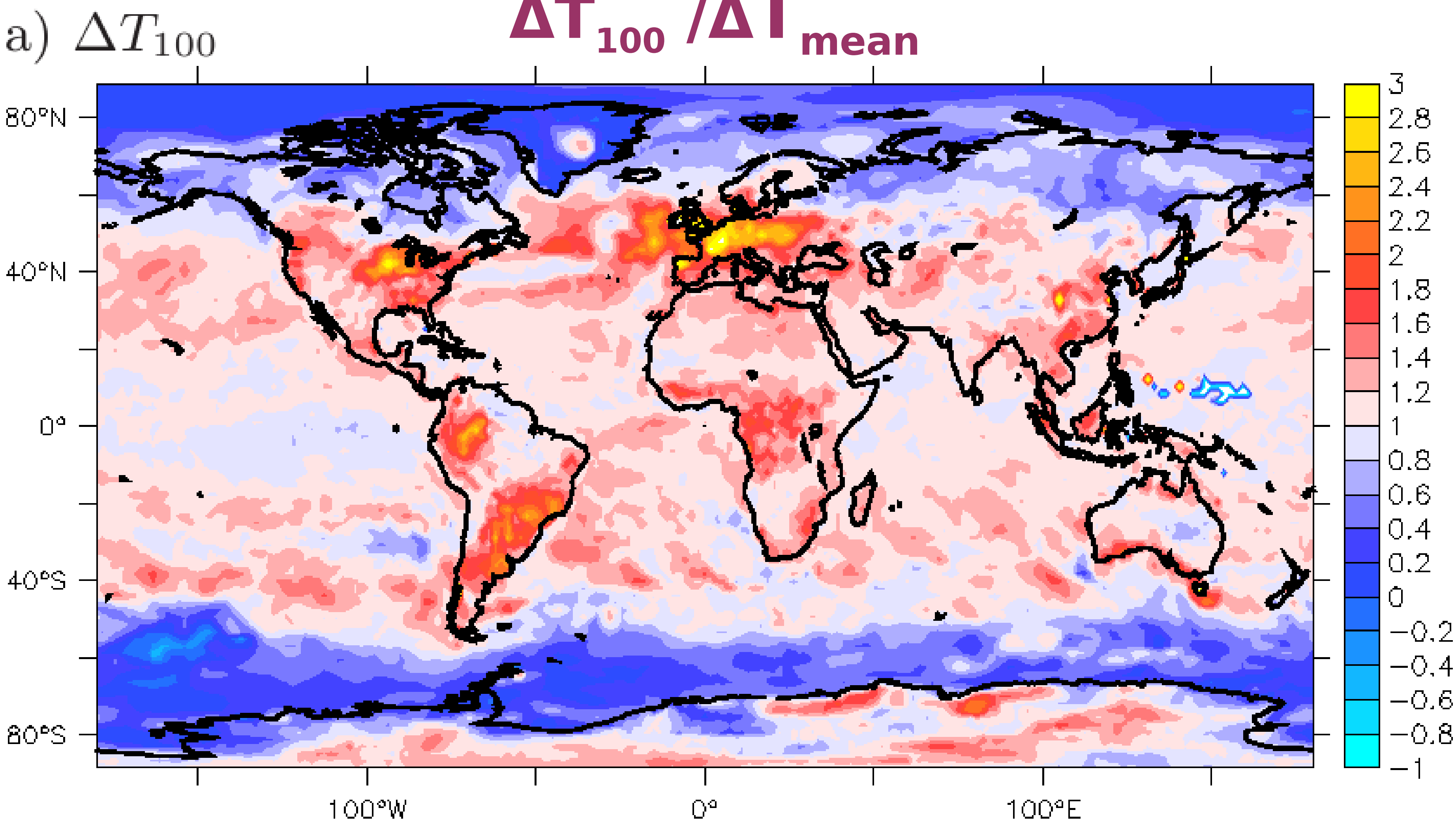
Joint probabilities

e.g., heavy rain + surge at same time

Changes of extremes

shift (μ) or change of shape (σ and/or ξ)?

$\Delta T_{100} / \Delta T_{mean}$



Conclusions

- Extremes are important (vulnerability)
- Rare events => small numbers
- Moderate or soft extremes (~ once per year)
  - Simple climate indices
  - Easy to determine (just count)
- Extreme extremes ($p < \sim 0.1/y$)
  - EVT, well established
  - extrapolation possible (long return times)
  - Confidence intervals
  - Time dependence

THE END !!!