INTRO – Claire the Climate Scientist

What is she doing? (everyday work of a climatologist)

- Claire lives in a world with a CESM 1.2.2 (2° Resolution) climate and no global change
- She studies the frequency and severity of heat extremes
- She relies on extreme value theory – or more specifically the block-maxima approach – to estimate quantities like return levels or return periods
- Currently, she investigates a 100yr long observational time series of daily maximum temperature data

IAC Institute for Atmospheric and Climate Science

INTRO – Claire the Climate Scientist
What is her concern?

How would her estimates change if she …

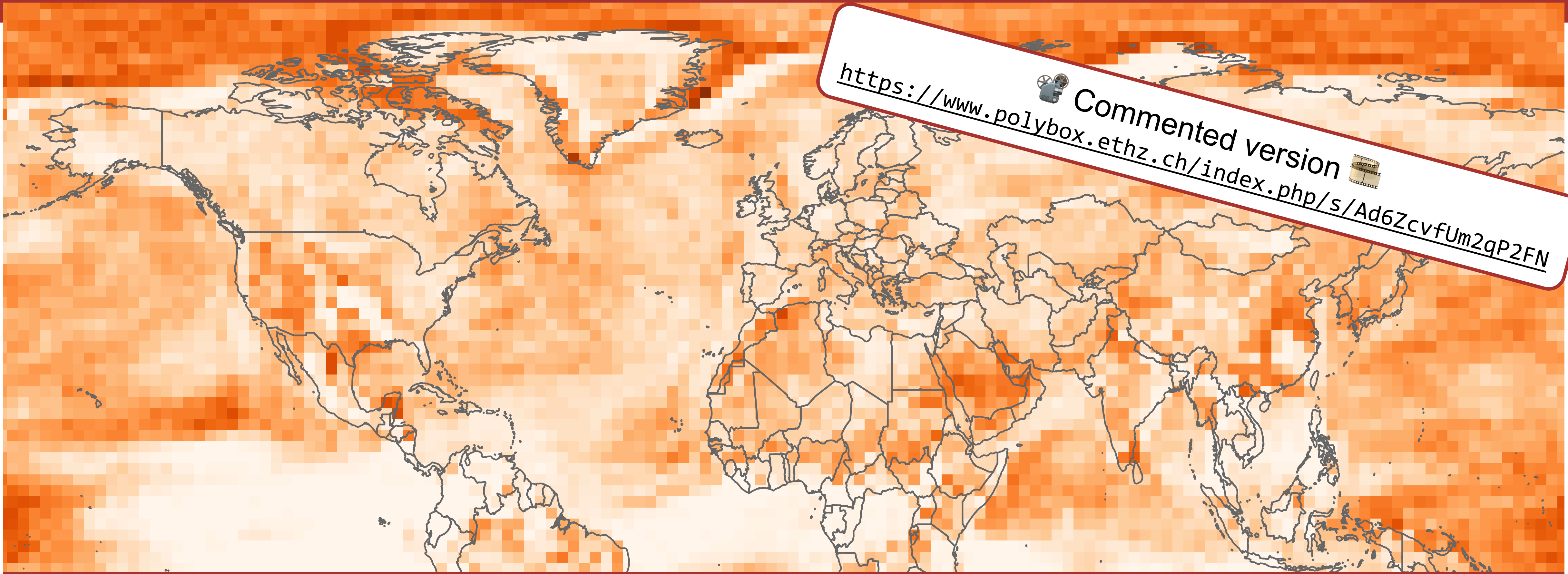
- … had more data to investigate?
  (if only one had measured temperature for more than just 100 years)
- ... would choose a larger than annual block size?
  (are annual maxima extreme enough to be analysed with EVT?)
- ... knew the effects of internal climate variability?
  (what if she did the analysis 100 years ago?)

INTRO – Claire the Climate Scientist
What would she find?

Sometimes at night she dreams about having thousands of years of data available to answer these questions. She would find that …

- … return levels of heat extremes are slightly underestimated when using a limited amount of data.
- … confidence intervals as measures of uncertainty should be regarded as lower bound estimates of the total uncertainty.
- … the (true) frequency of extreme events is very often massively underestimated.

ETH zürich



Commented version
https://www.polybox.ethz.ch/index.php/s/Ad6ZcvfUm2qP2FN

The Challenge of Estimating High Return Levels with Short Records under Large Internal Variability

EGU Session on Large Ensembles

IAC Institute for Atmospheric and Climate Science

Claire the Climate Scientist
Motivation

Model:
- CESM 1.2.2 (2° Resolution)
- Pre-industrial control run
- and further CMIP6 models

Target variable:
- Tx7d (Maximum 7d temperature mean)
- and Rx1d & Rx5d (max 1-/5-day precipitation)

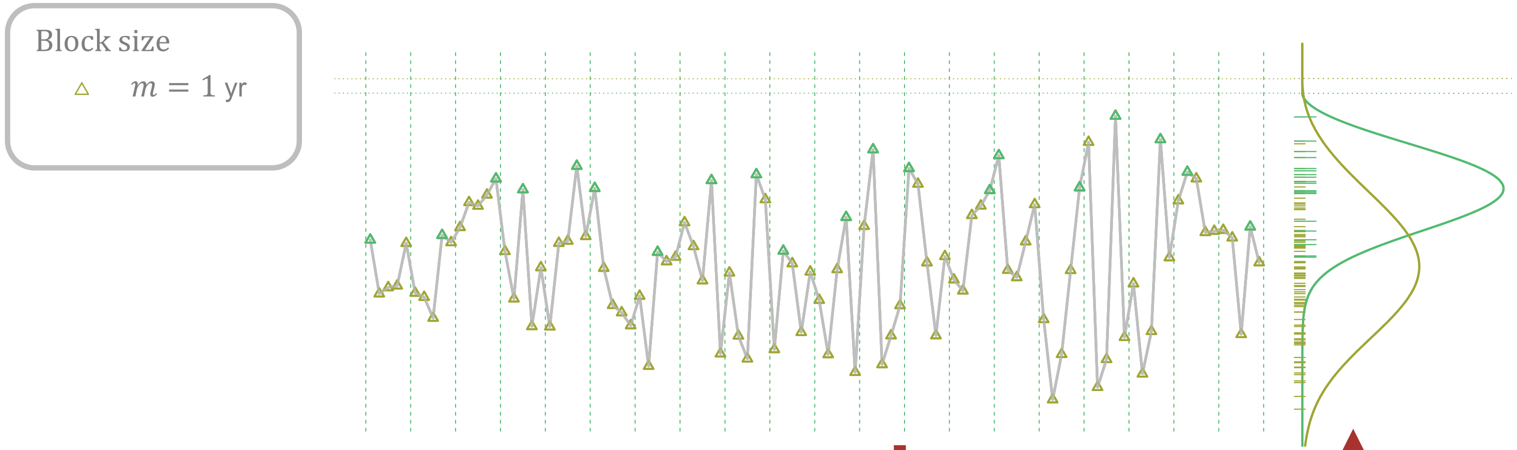
Research focus:
- Return level and return period estimates for Maxima under different
  - time series durations t_{sub} or
  - block sizes m

IAC Institute for Atmospheric and Climate Science

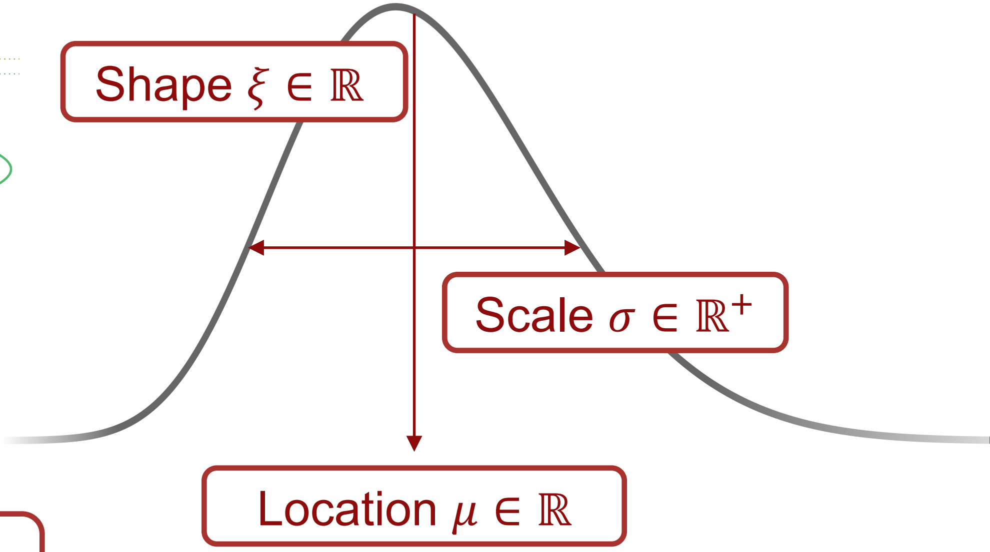
Generalised Extreme Value Distribution $G(x;\mu,\sigma,\xi)$

Recap in Extreme Value Theory

- Statistical distribution of maxima taken from blocks (length m) of iid data
- E.g. highest daily temperature in consecutive five year blocks ($m = 5\mathrm{yr}$) from 1901 to 2000 ($t_{sub} = 100\mathrm{yr}$), i.e. 1901-1905, 1906-1910, …, 1996-2000



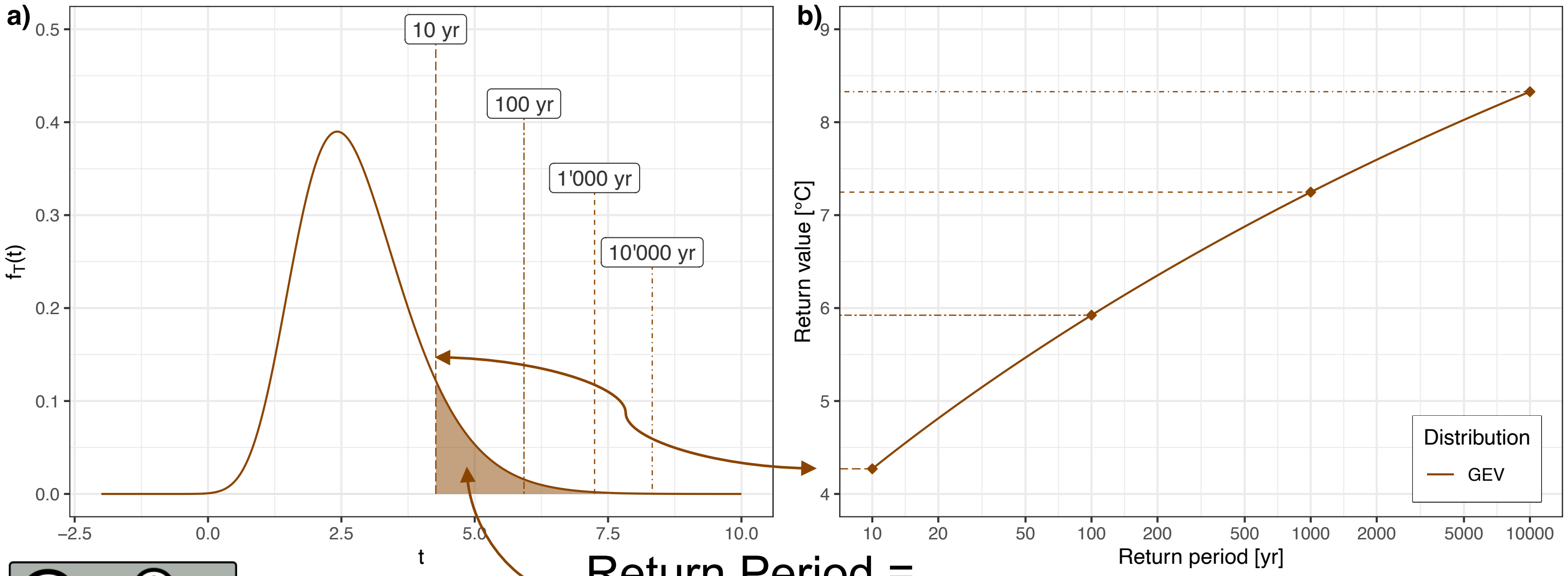
ML fit of $G_m(x;\mu,\sigma,\xi)$



Generalised Extreme Value Distribution $G(x;\mu,\sigma,\xi)$
Recap in Extreme Value Theory

- Having estimated the model parameters $\hat{\mu},\hat{\sigma},\hat{\xi}$, we can infer the respective return levels z_p for specified return periods $1/p$:

$$\hat{z}_p(\hat{\mu},\hat{\sigma},\hat{\xi}) = \hat{\mu} - \frac{\hat{\sigma}}{\hat{\xi}}\left[1-(-\log(1-p))^{-\hat{\xi}}\right]$$

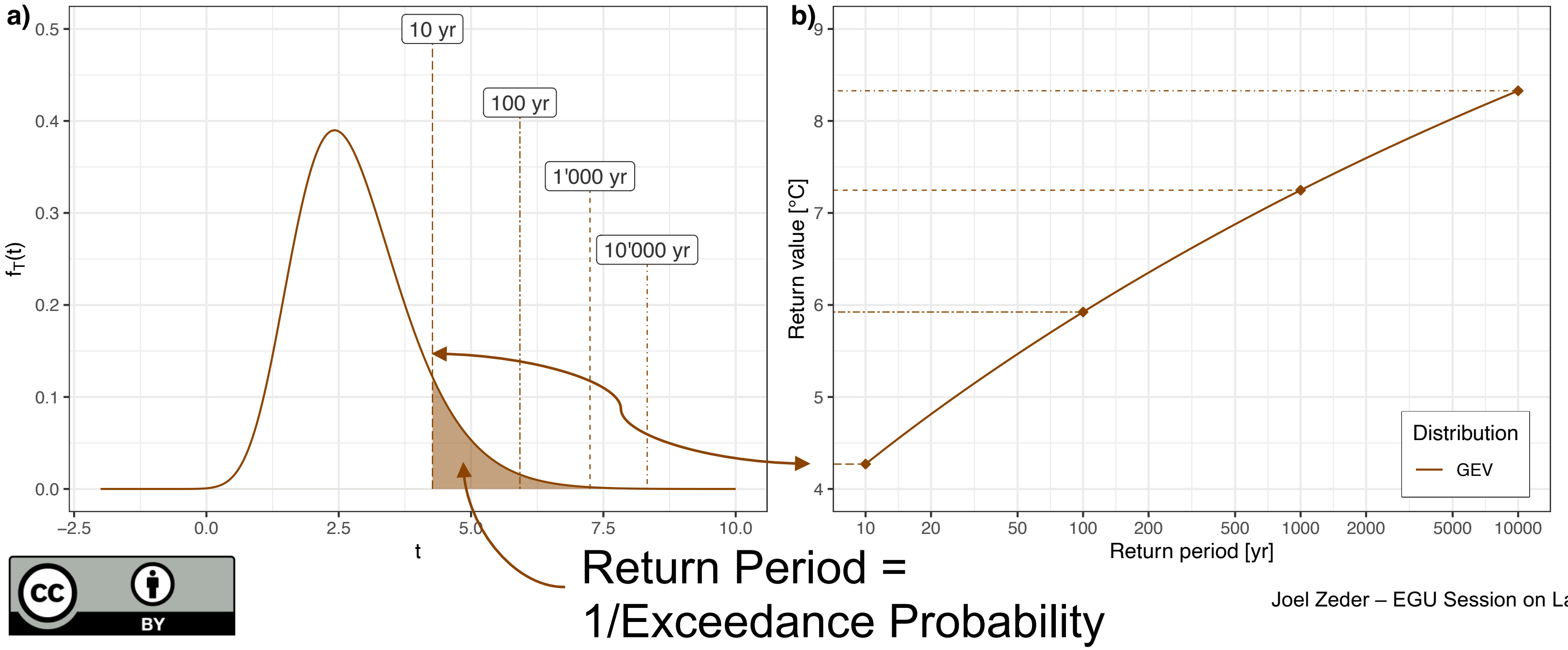


Return Period =
1/Exceedance Probability

Generalised Extreme Value Distribution $G(x;\mu,\sigma,\xi)$
Recap in Extreme Value Theory

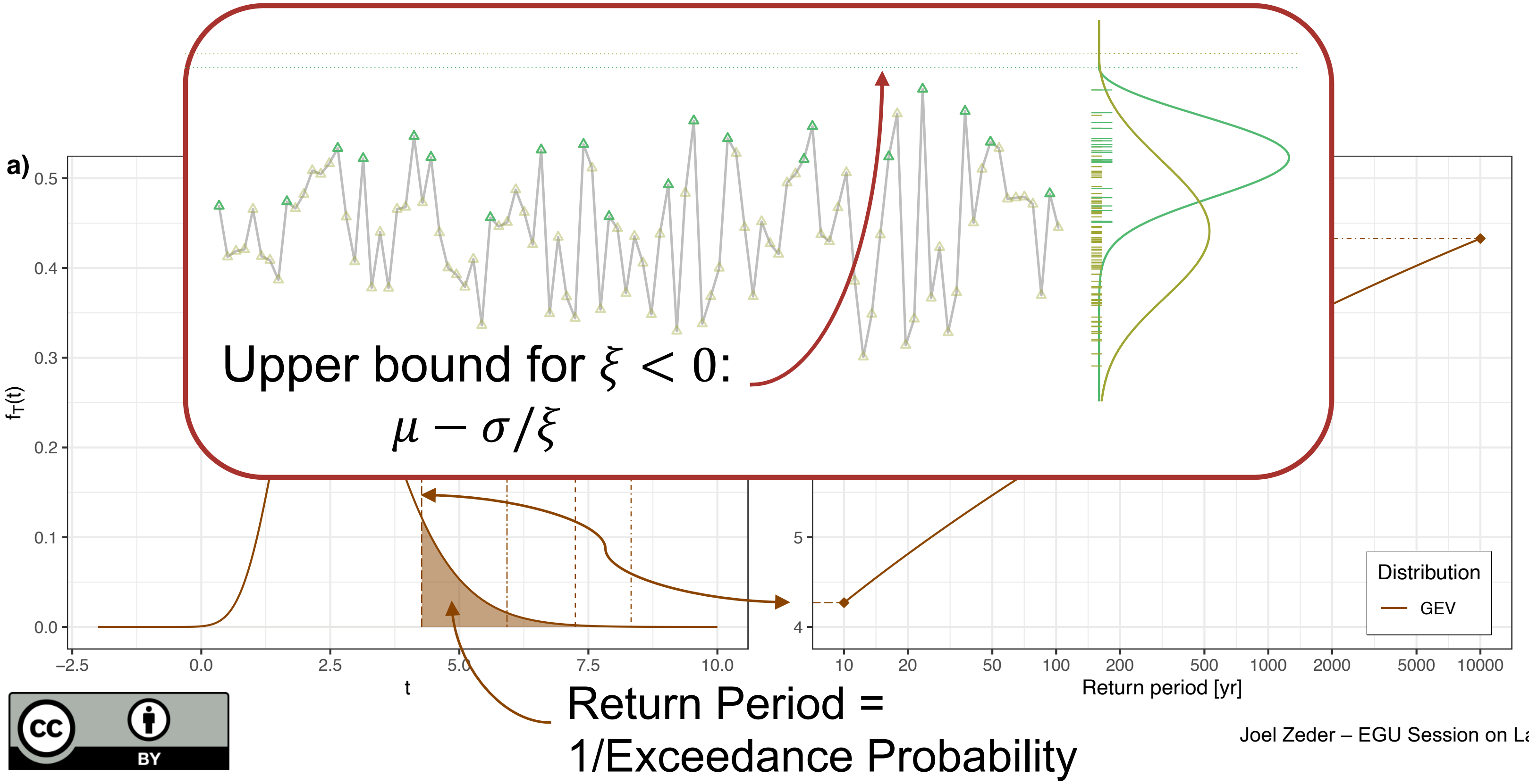
- Having estimated the model parameters $\hat{\mu},\hat{\sigma},\hat{\xi}$, we can infer the respective return levels z_p for specified return periods $1/p$:

$$\hat{z}_p(\hat{\mu},\hat{\sigma},\hat{\xi}) = \hat{\mu} - \frac{\hat{\sigma}}{\hat{\xi}}\left[1-\left(-\log(1-p)\right)^{-\hat{\xi}}\right]$$



Generalised Extreme Value Distribution $G(x; \mu, \sigma, \xi)$
Recap in Extreme Value Theory

- Having estimated the model parameters $\hat{\mu}, \hat{\sigma}, \hat{\xi}$, we can infer the respective return levels z_p for specified return periods $1/p$:

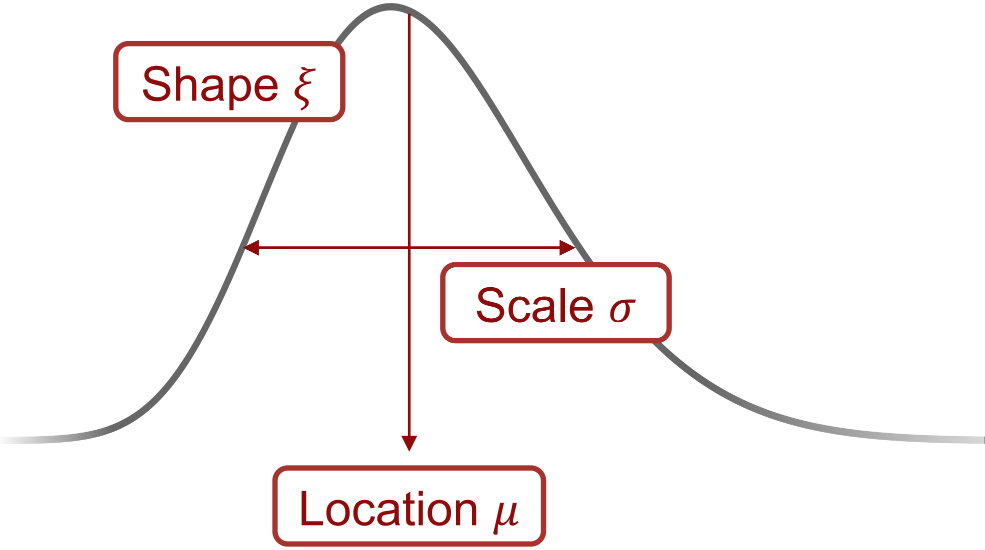


Research Objective

How do estimates of model parameters (μ, σ, ξ), return values $(100/200/500/1000\mathrm{yr})$ and exceedance probabilities (i.e. return periods) depend on

- block size $(m = 1, 5, 20\mathrm{yr})$ and
- time series length $(t_{sub} = 50, 100, 500, 1000\mathrm{yr})$

under the influence of internal variability?



Extremes in a Stationary (Model) Climate

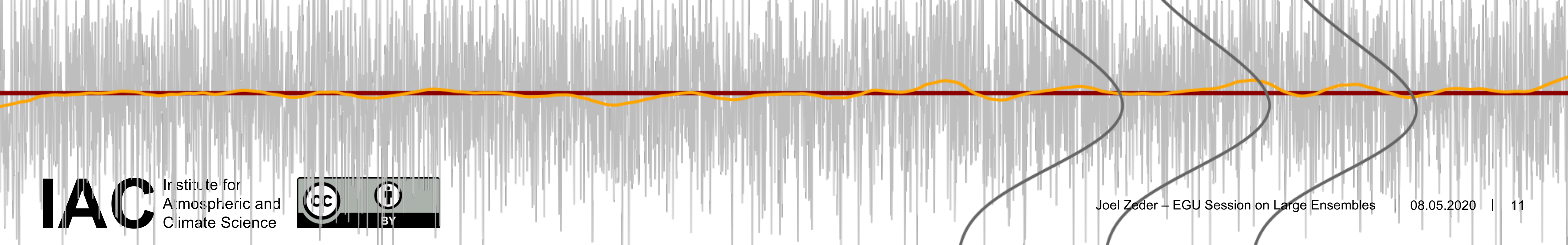
Focus on internal variability → Analyse extremes in stationary model climate

The climatological perspective:

- No external forcing, only internal variability

The statistical perspective:

- Realisations from a stationary distribution (with constant parameters $G(x; \boldsymbol{\mu}, \boldsymbol{\sigma}, \boldsymbol{\xi})$?)



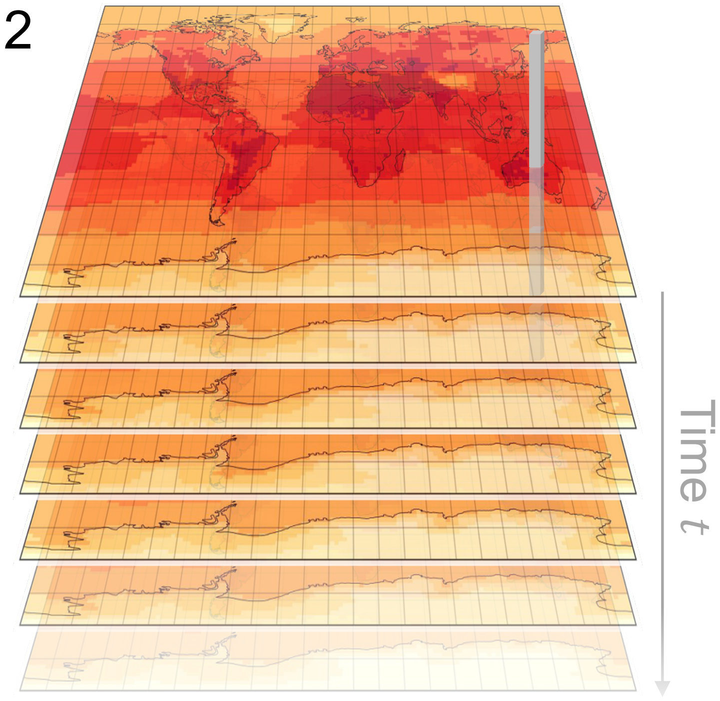
IAC Institute for Atmospheric and Climate Science

Claire the Climate Scientist

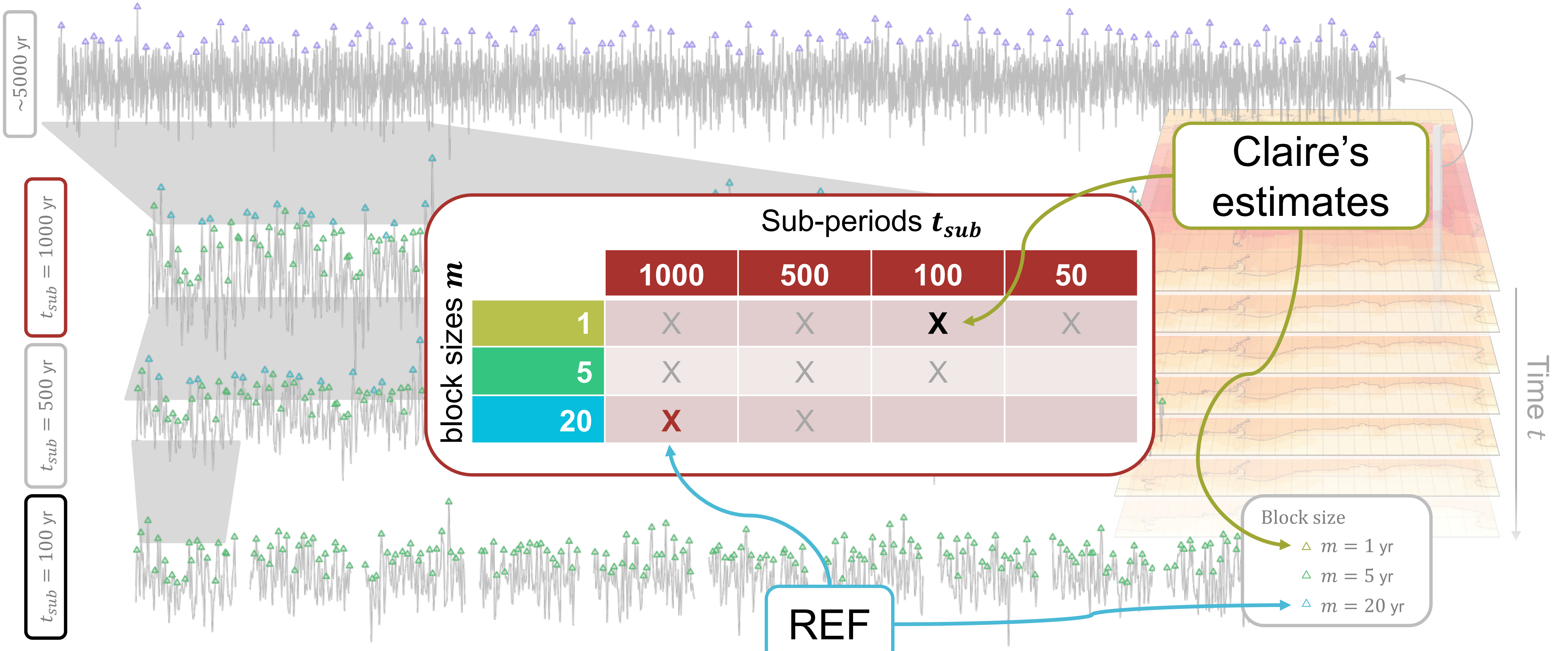
Motivation

Data form CESM12 pre-industrial control run:

- 7day maxima of surface temperature
- at each grid point
- for ~5000yr model years



Sub-periods t_{sub} and block sizes m



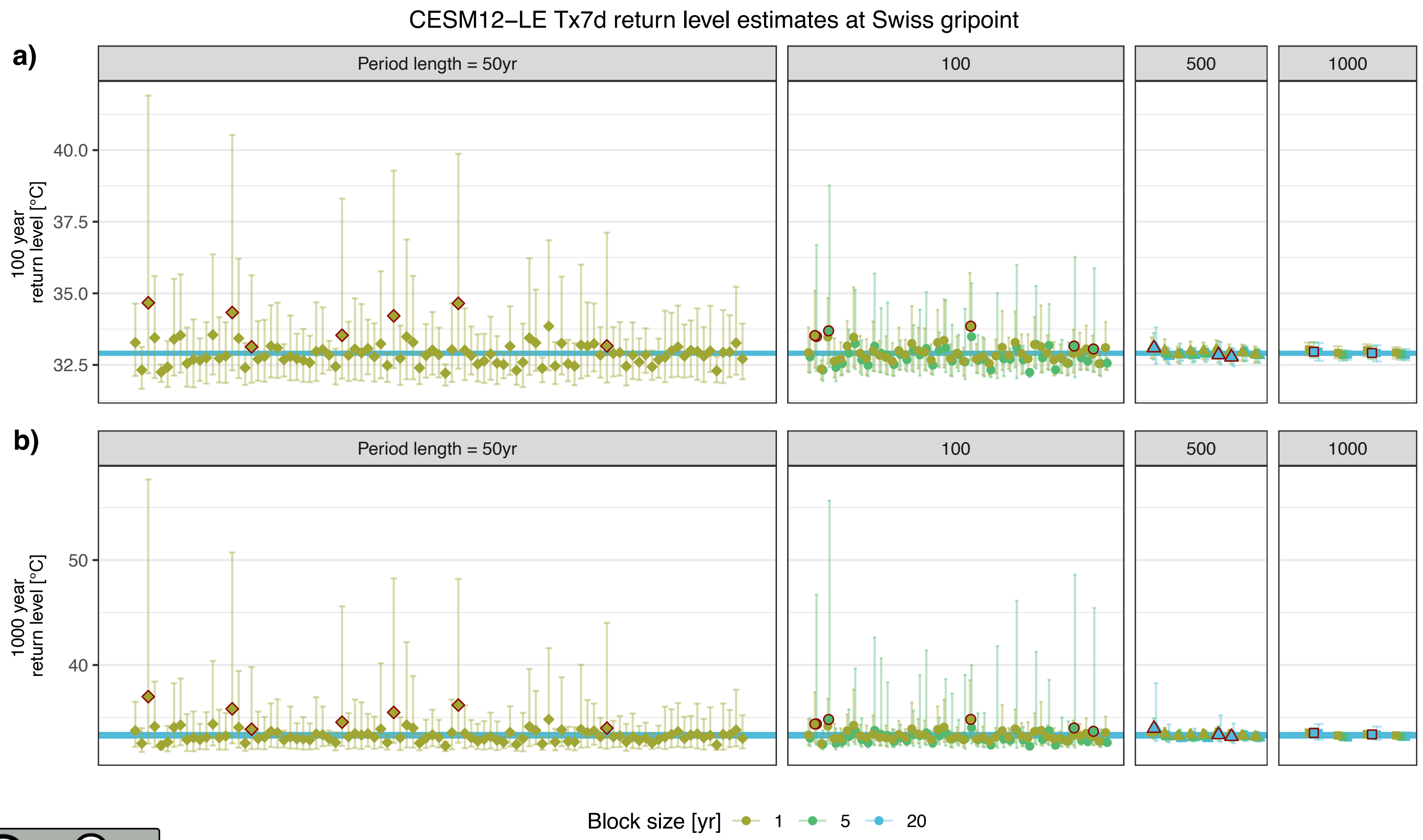
Sub-periods t_{sub}

block sizes m	1000	500	100	50
1	X	X	**X**	X
5	X	X	X	
20	X	X		

Estimated Tx7d GEV return levels at Swiss grid point

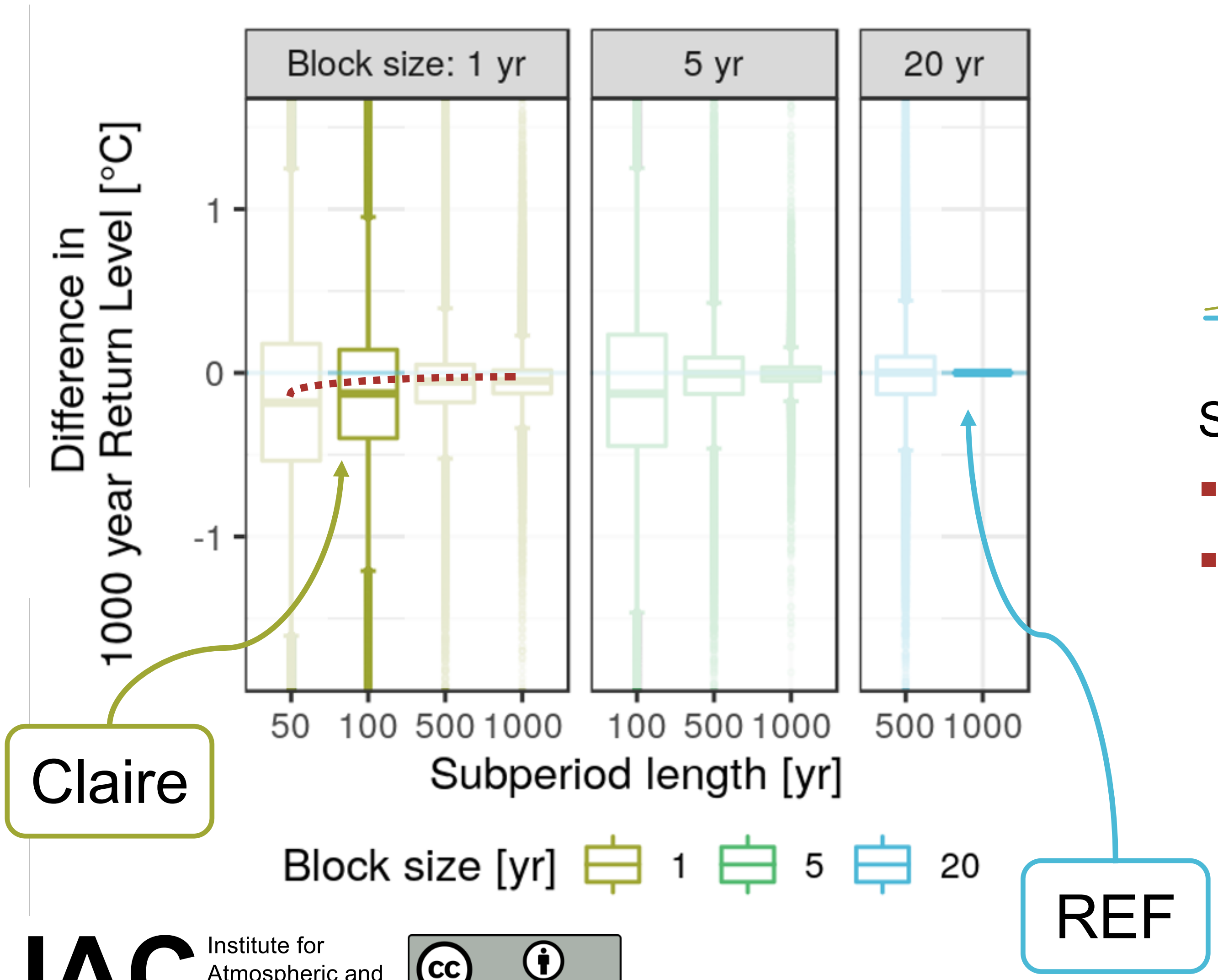
100 year
return level [°C]

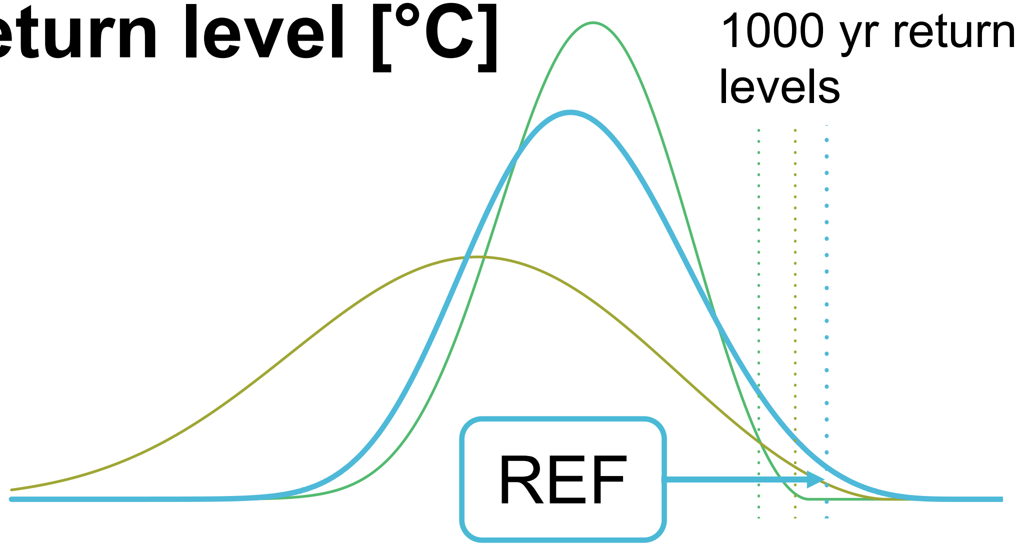
1000 year
return level [°C]



REF

1. Systematic underestimation of return level [°C]





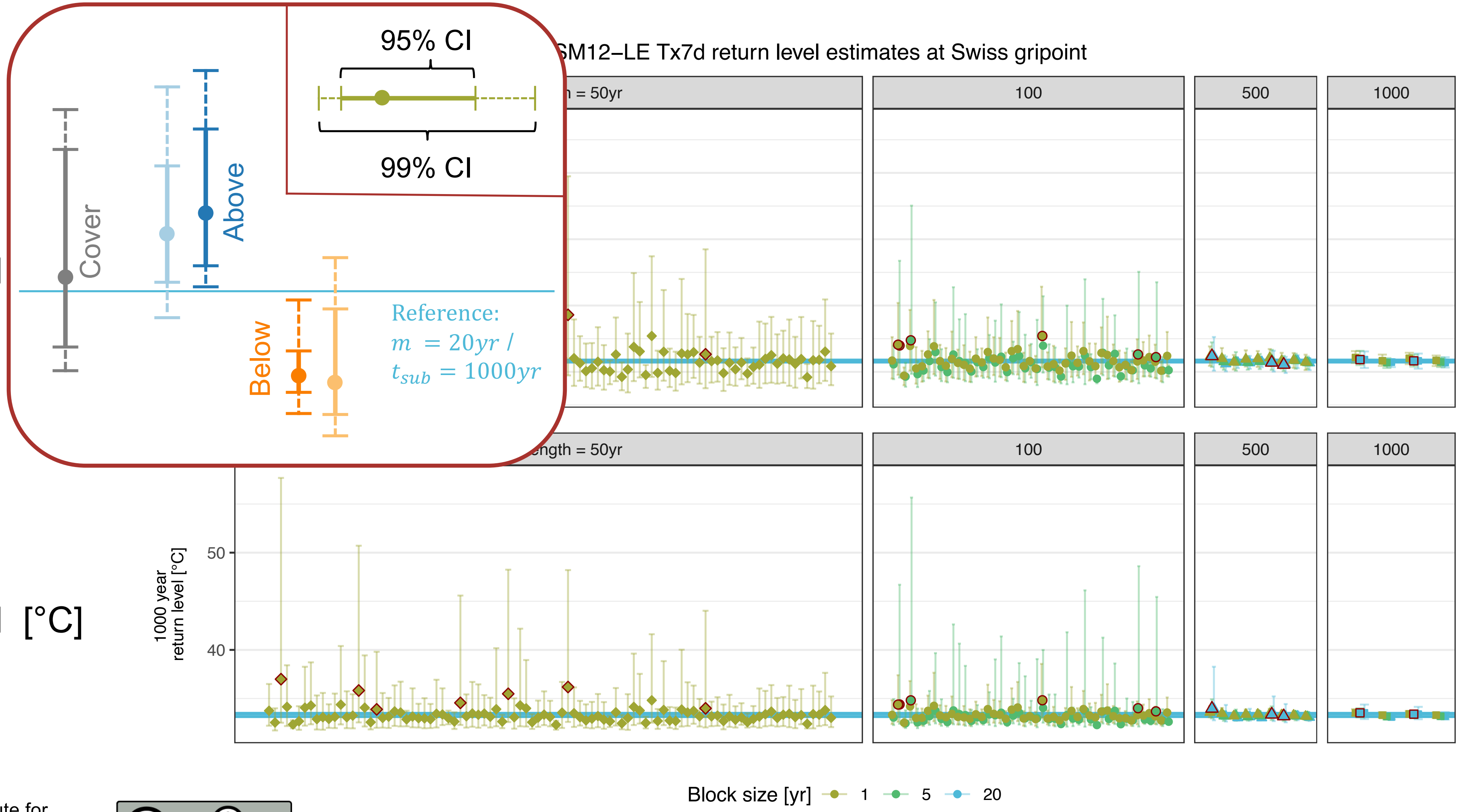
Small systemic underestimation of return levels

- observable for shorter sub-periods t_{sub}
- not so much for smaller block sizes m

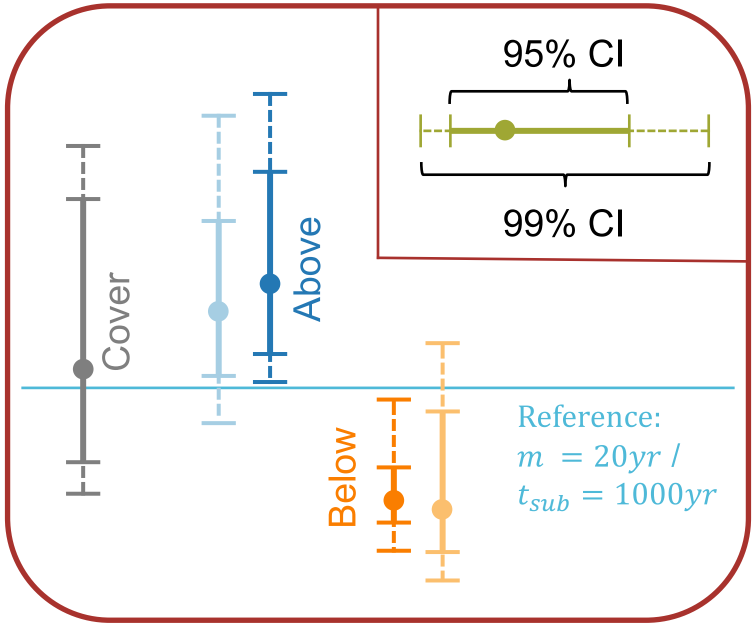
CI of estimated Tx7d GEV return levels at Swiss grid point

100 year
return level

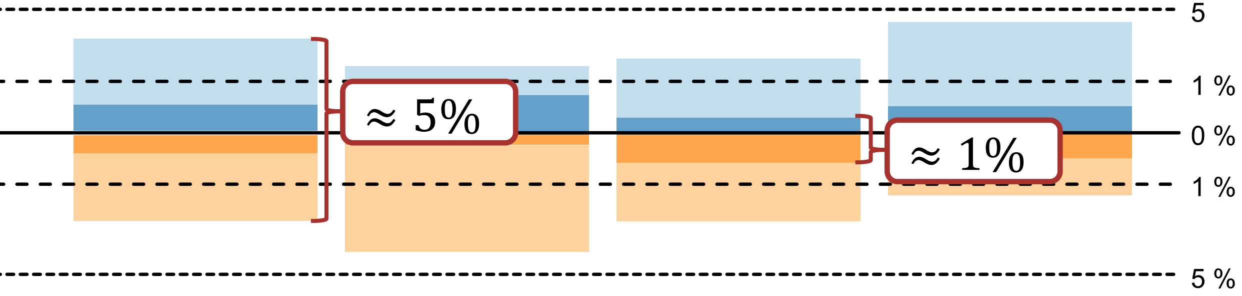
1000 year
return level [°C]

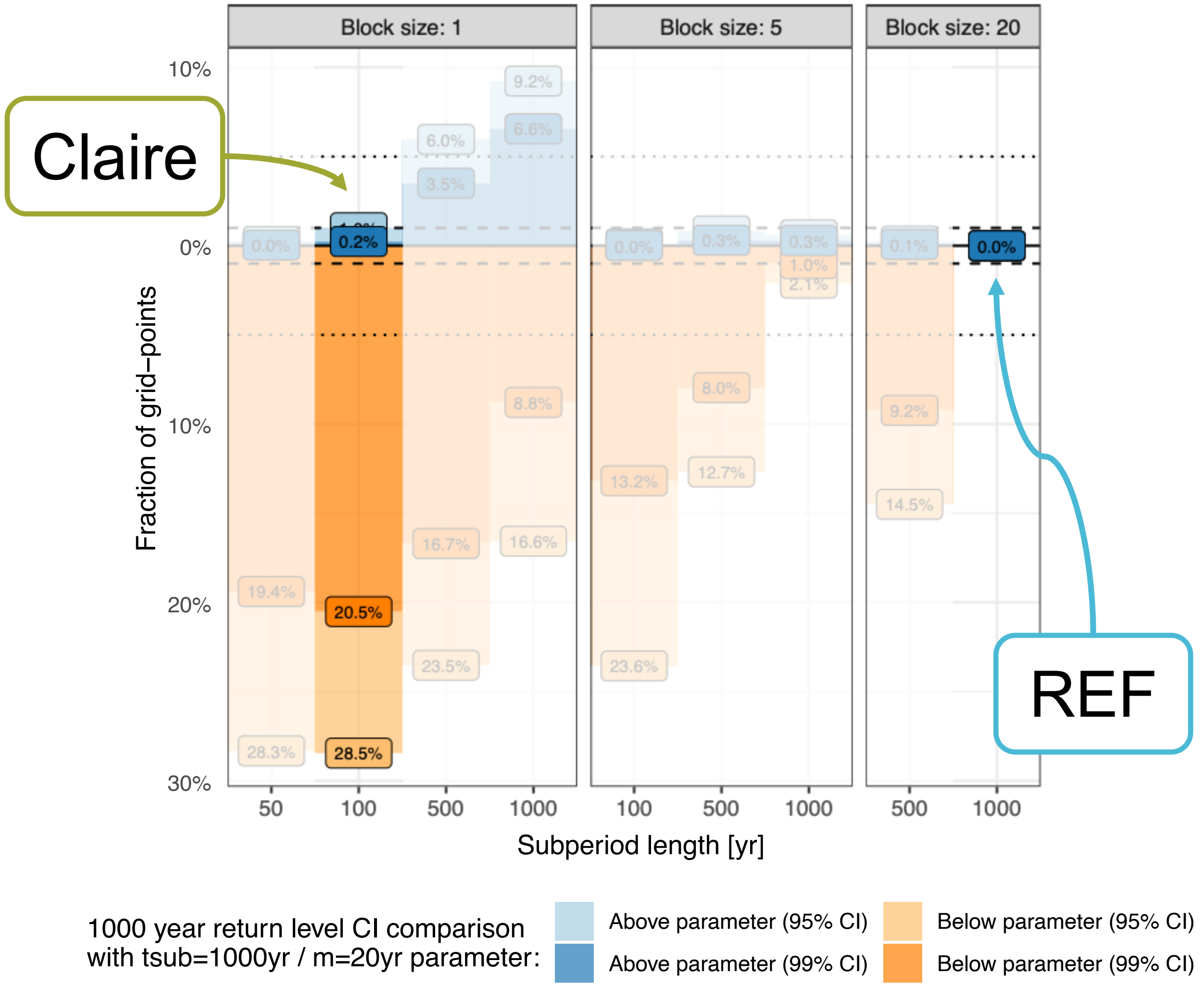


2. CI coverage of 1000yr return level reference estimate



Expectation from theory:

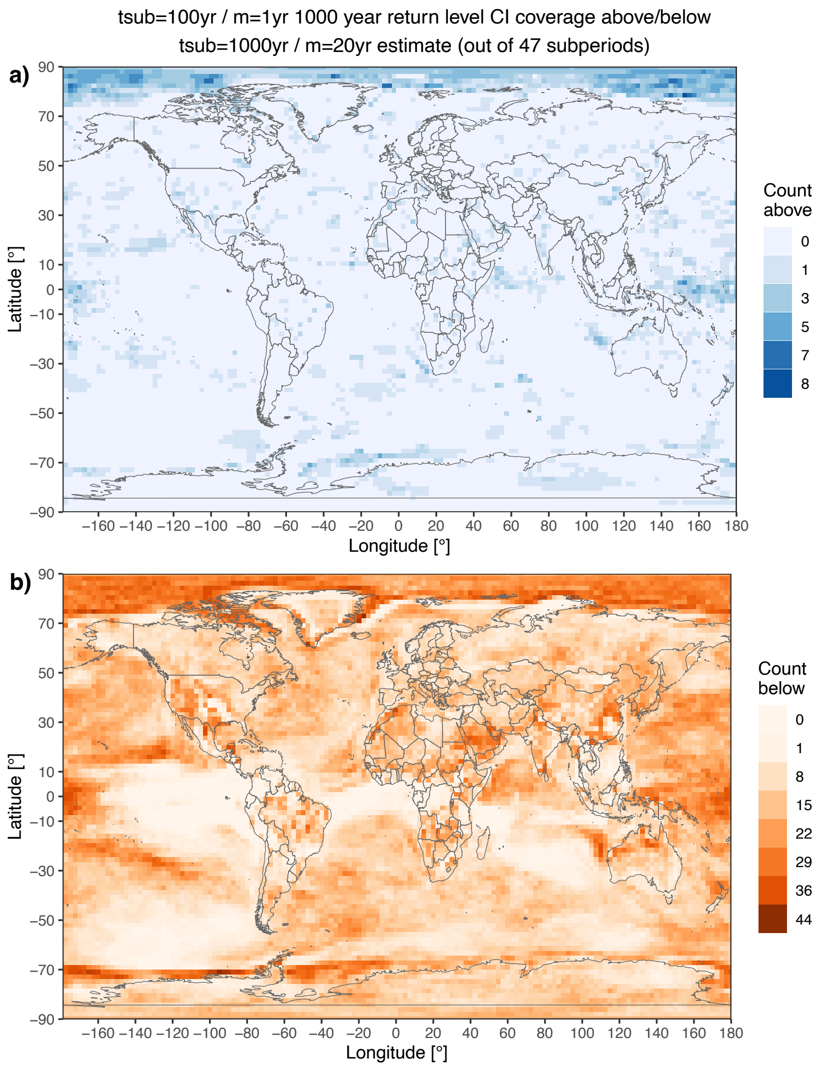


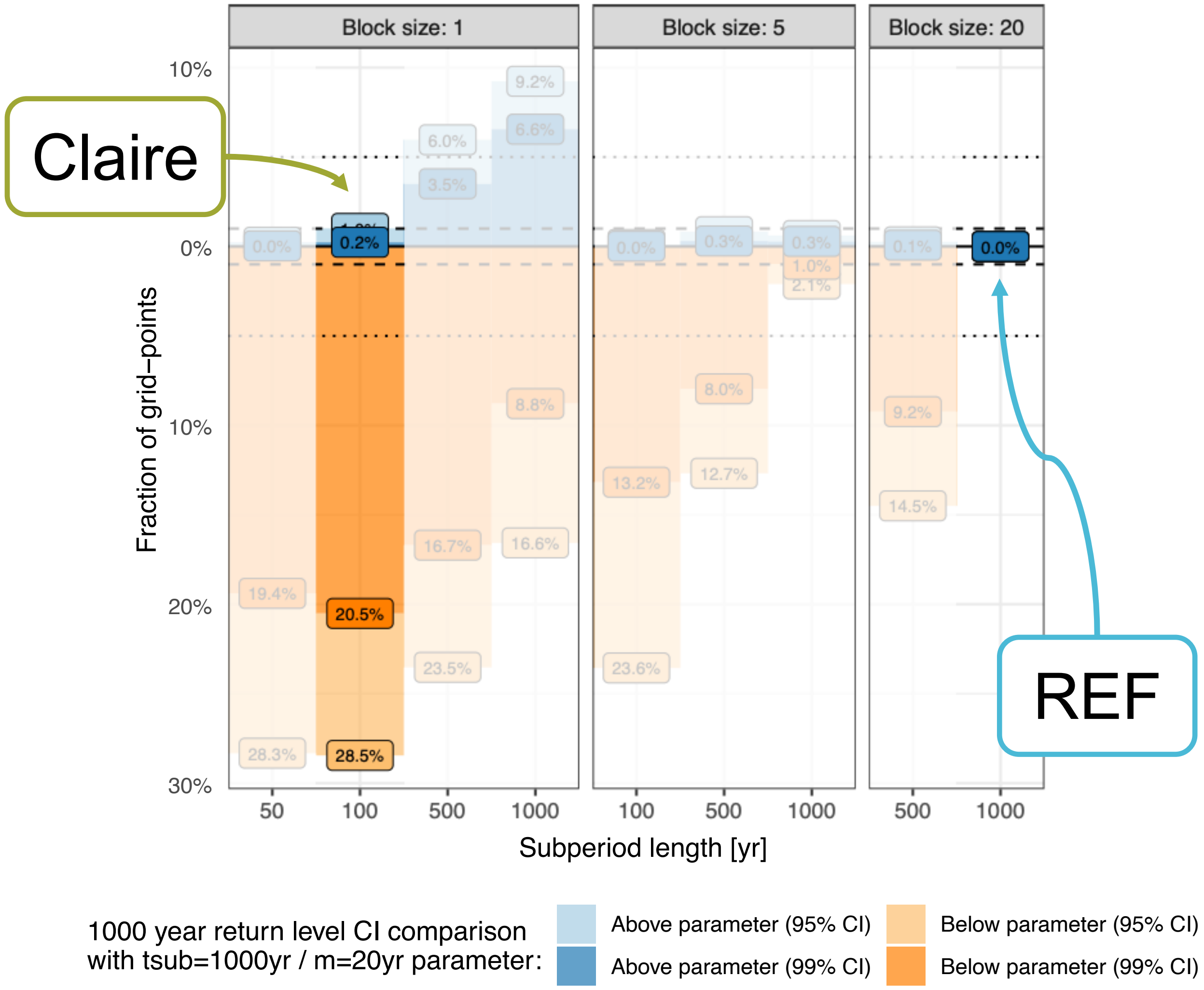


IAC Institute for Atmospheric and Climate Science

ETH zürich

2. CI coverage of 1000yr return level reference estimate

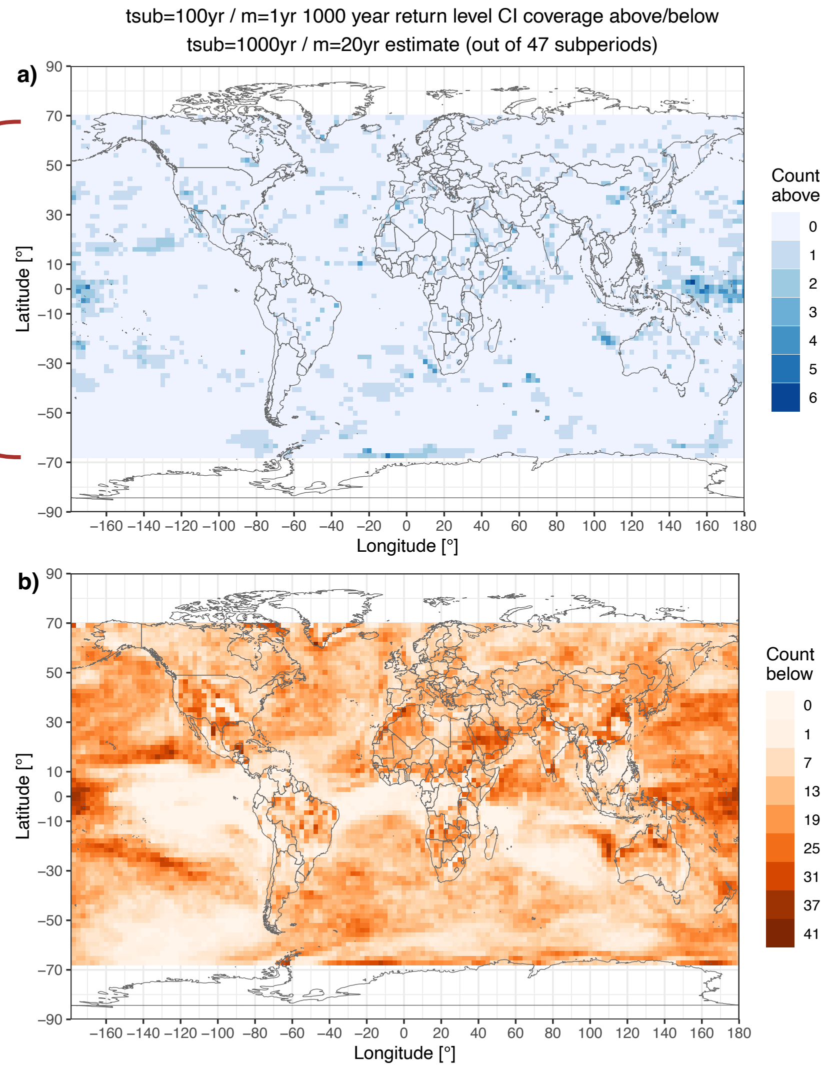


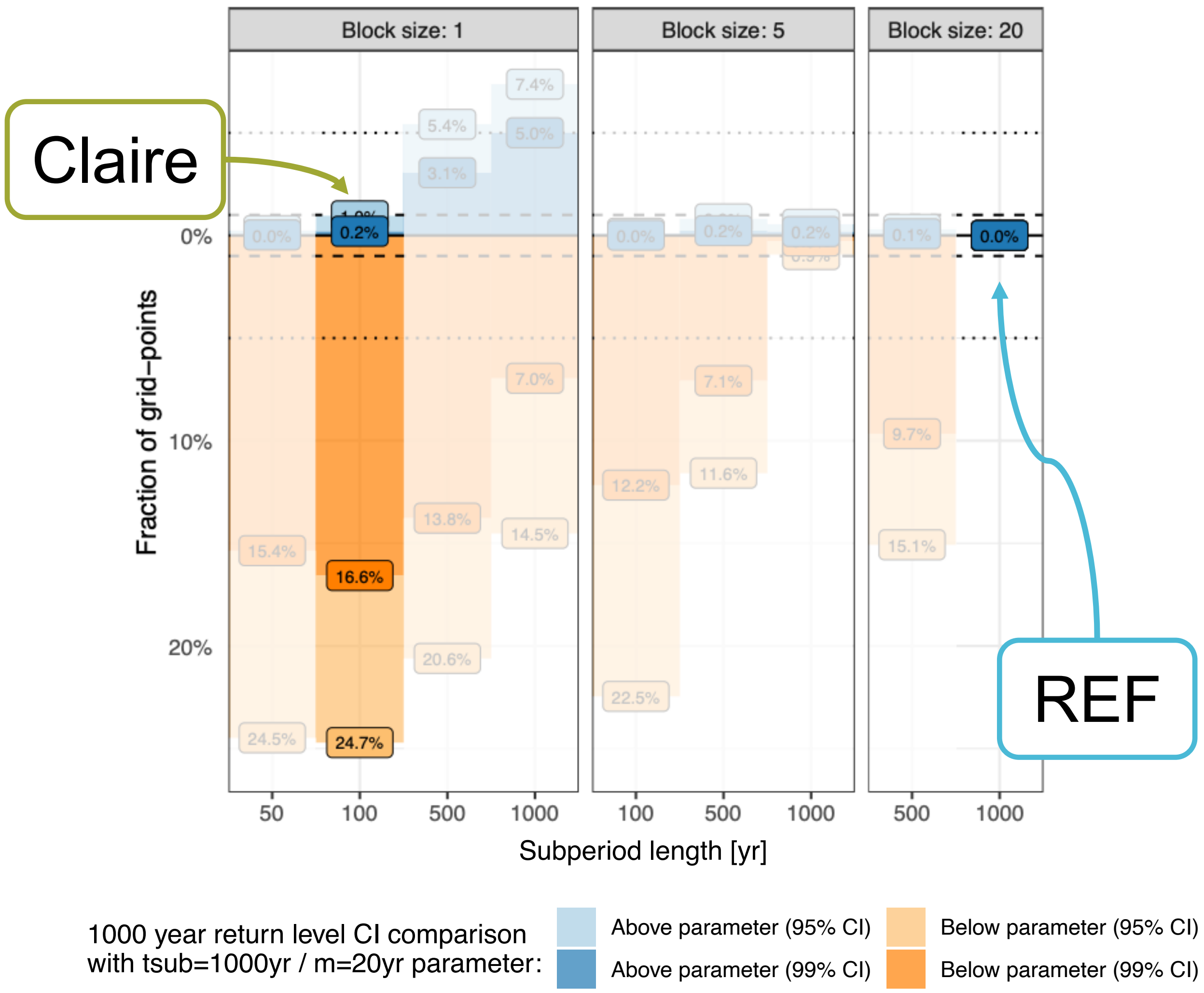


IAC Institute for Atmospheric and Climate Science

2. CI coverage of 1000yr return level reference estimate

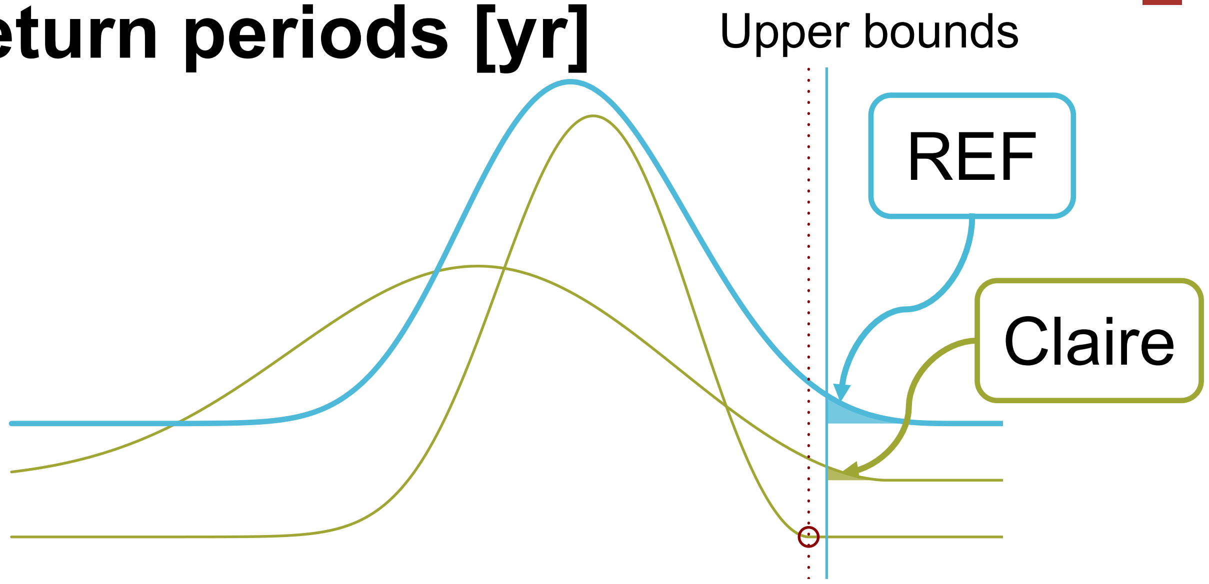
Only low latitudes

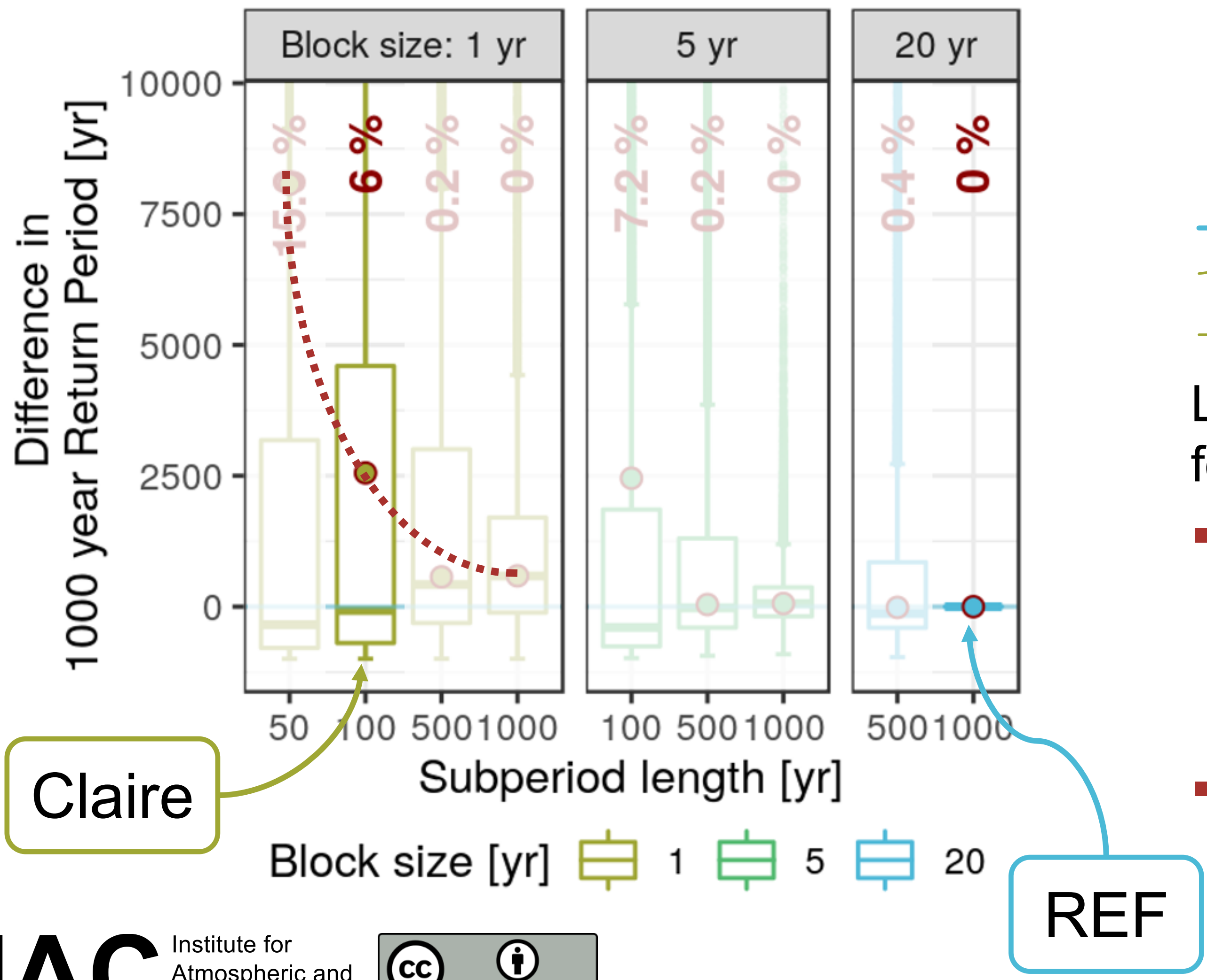




IAC Institute for Atmospheric and Climate Science

3. Systematic underestimation of return periods [yr]





Large systemic overestimation of return periods for high return levels in the reference data:

- The median return period of a 1000 yr reference return level is estimated to be a ~3500 yr return level for $t_{sub} = 100yr$ and $m = 1yr$ fits.
- In 6% of $t_{sub} = 100yr$ and $m = 1yr$ fits, the 1000 yr reference return level has a return period of infinity.

IAC Institute for Atmospheric and Climate Science

Conclusions and Outlook

Even under stationary conditions,

- ✓ high return values are often underestimated and return periods are overestimated by fitting on small block sizes and short time series.
- ✓ Confidence intervals are often not covering the refence value and thus underestimate uncertainty of the estimate.

The same findings can be concluded for transient LE CESM12 data, other CMIP6 control run simulations and using $m = \mathbf{5}\mathrm{yr}$ / $t_{sub} = 1000\mathrm{yr}$ estimates as reference.

Outlook:

- ❑ Extend analysis to non-stationary **transient** LE simulations.

Thank you very much for your attention

- Joel Zeder, PhD Candidate
  joel.zeder@env.ethz.ch / @JoelZeder

- Dr. Erich Fischer, Senior Scientist
  erich.fischer@env.ethz.ch / @erichfischer

ETH Zurich
Climate Physics Group of Prof. Reto Knutti
Institute for Atmospheric and Climate Science
Universitätstrasse 16
8092 Zurich
Switzerland

Also have a look at the presentation of Claudia Gessner, working on a similar project:
https://meetingorganizer.copernicus.org/EGU2020/EGU2020-1628.html

IAC Institute for Atmospheric and Climate Science