CLIMXTREME Climate Change and Extreme Events

Freie Universität Berlin

Extreme Precipitation in the past and future

Non-stationary Large-Scale Statistics of Precipitation Extremes in Central Europe

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Felix S. Fauer
Henning W. Rust

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Mother Jones

Smart, F

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ENVIRONMENT JULY 21, 2023

The Problem With Calling Vermont's Storms a "100-Year-Flood"

Thanks to climate change, these deluges are occurring much more often.

JACKIE FLYNN MOGENSEN
Reporter
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Tyler Jovic, of Montpelier, carries his neighbor's dog to dry ground on July 11, 2023
Washington Post/Getty

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'100 year-event': Denmark braced for extreme torrential rain this weekend

Michael Barrett - michael@thelocal.dk
Published: 12 Jul, 2024 CET. Updated: Fri 12 Jul 2024 11:35 CET

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formation. Also, the new model enables insights into the

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Rain storm shatters records in N.S., called a "one-in-100 year event"

By Mark Hodgins
Posted Jul 23, 2023 12:32:49 PM. Last Updated Jul 24, 2023 02:16:35 PM.

100-year-event

- Static Climate?
- Changing Climate?

Motivation

to project small-scale extremes
(extreme precipitation)
difficult

vs.

to project large-scale average variables
(NAO, temperature, blocking, humidity)
easy

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1. Find relation:

Precipitation Intensity

Frequency

Large-scale average variable

2. Use future projection of large-scale variables (MPI-ESM)

2020 to 2100

3. Estimate future extremes

Use relation from the past

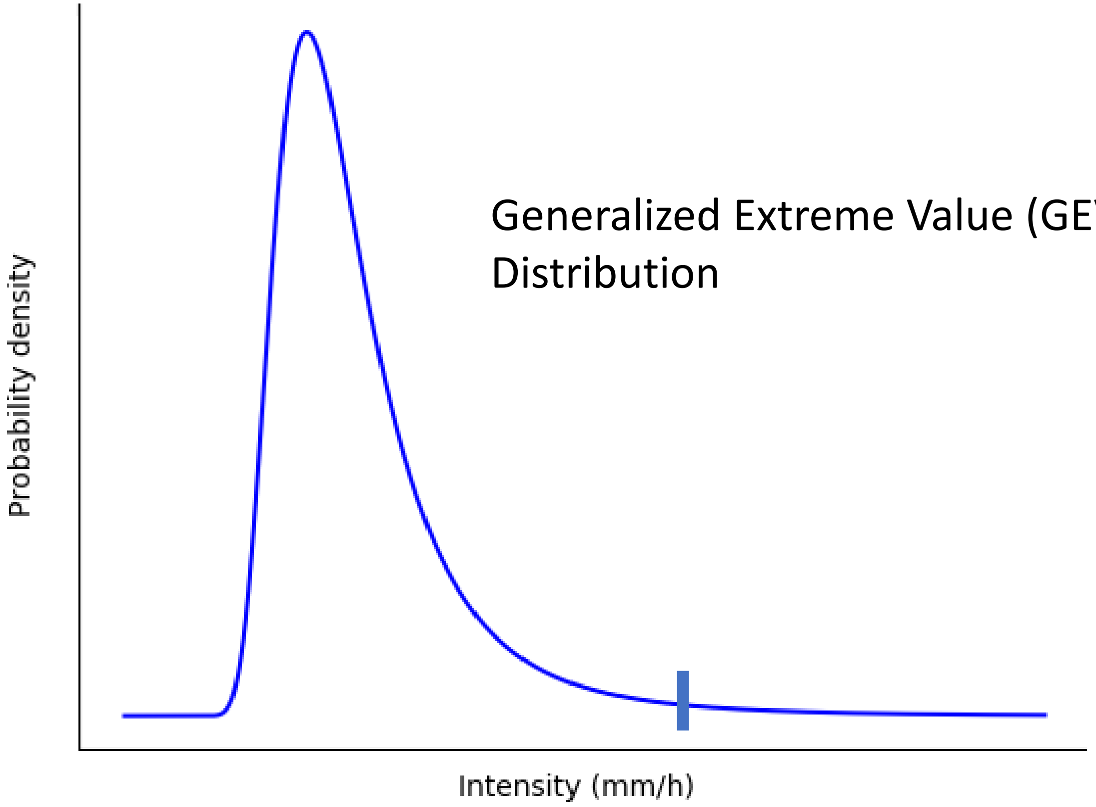
+

And future projection

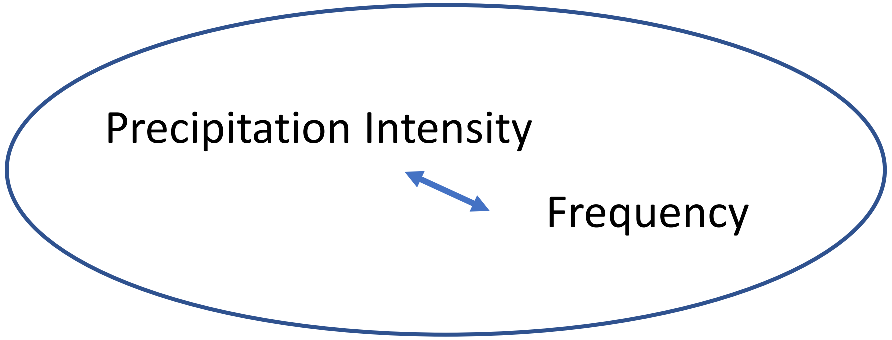
To estimate future extremes

Methods

Annual max. intensity: M_{2009} M_{2010} M_{2011} ...



Generalized Extreme Value (GEV) Distribution

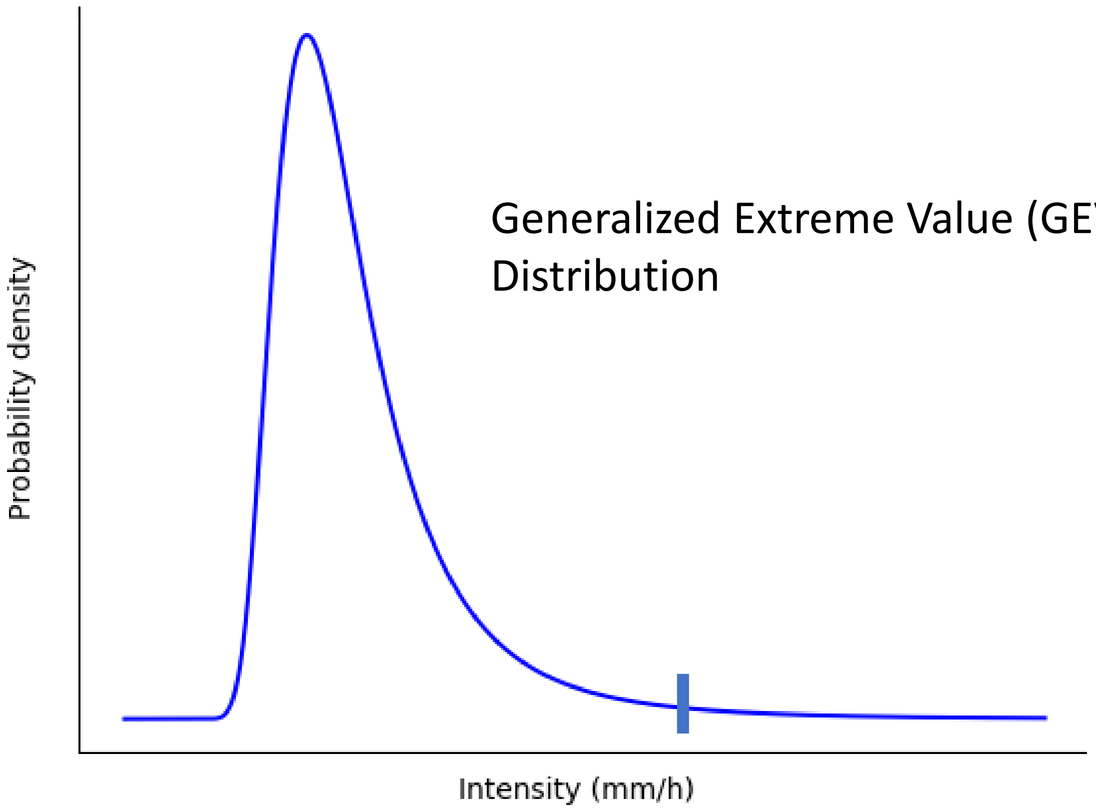


σ (scale)
μ (location)
ξ (shape)

Methods

Rain intensity daily time series

Annual max. intensity: M_{2009} M_{2010} M_{2011} ...



Generalized Extreme Value (GEV) Distribution

Precipitation Intensity ↔ Frequency

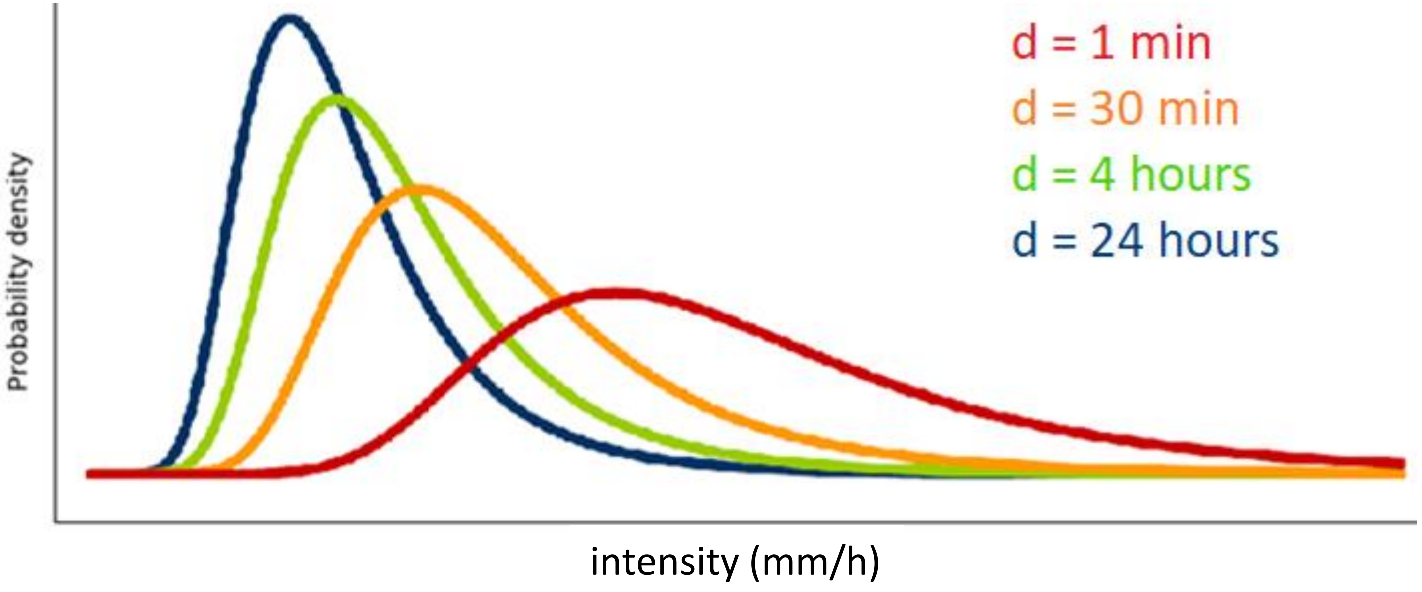
σ (scale)
μ (location)
ξ (shape)

Accumulated **daily** precipitation sums

Methods

Accumulated precipitation sums $\boldsymbol{d}$

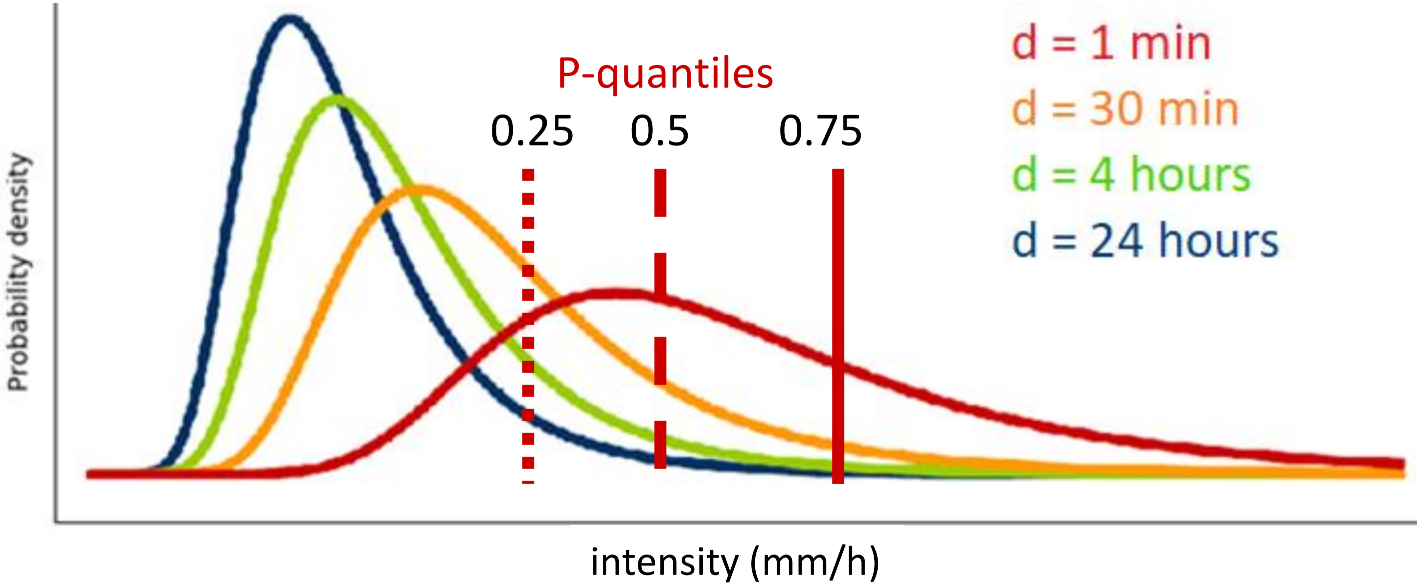
GEV - curves



Methods

Accumulated precipitation sums $\boldsymbol{d}$

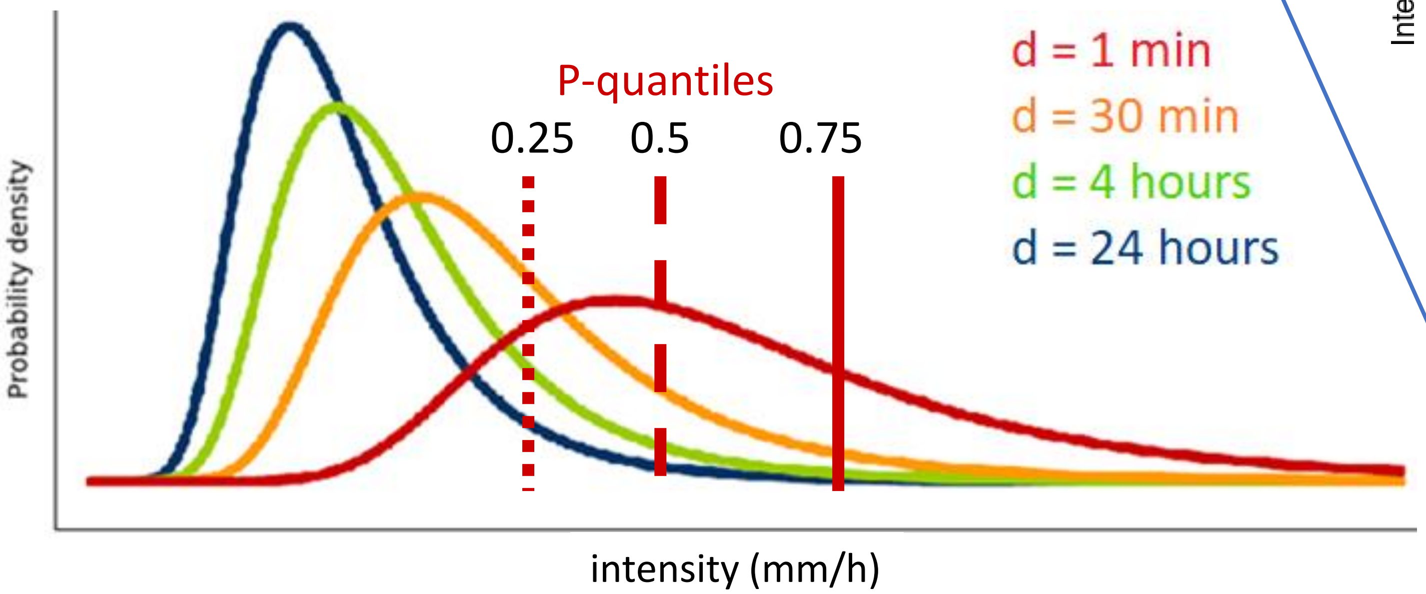
GEV - curves



Methods

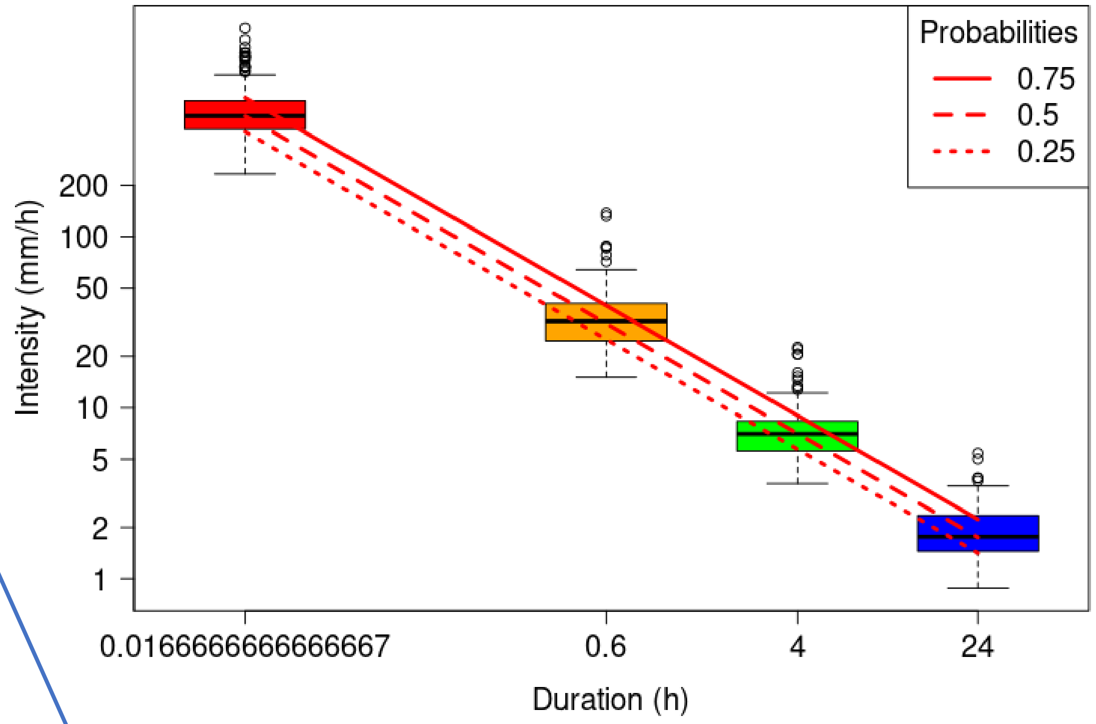
Accumulated precipitation sums d

GEV - curves



IDF curve

Intensity-duration-frequency



Smooth dependency
Duration → intensity

Methods

d-GEV

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

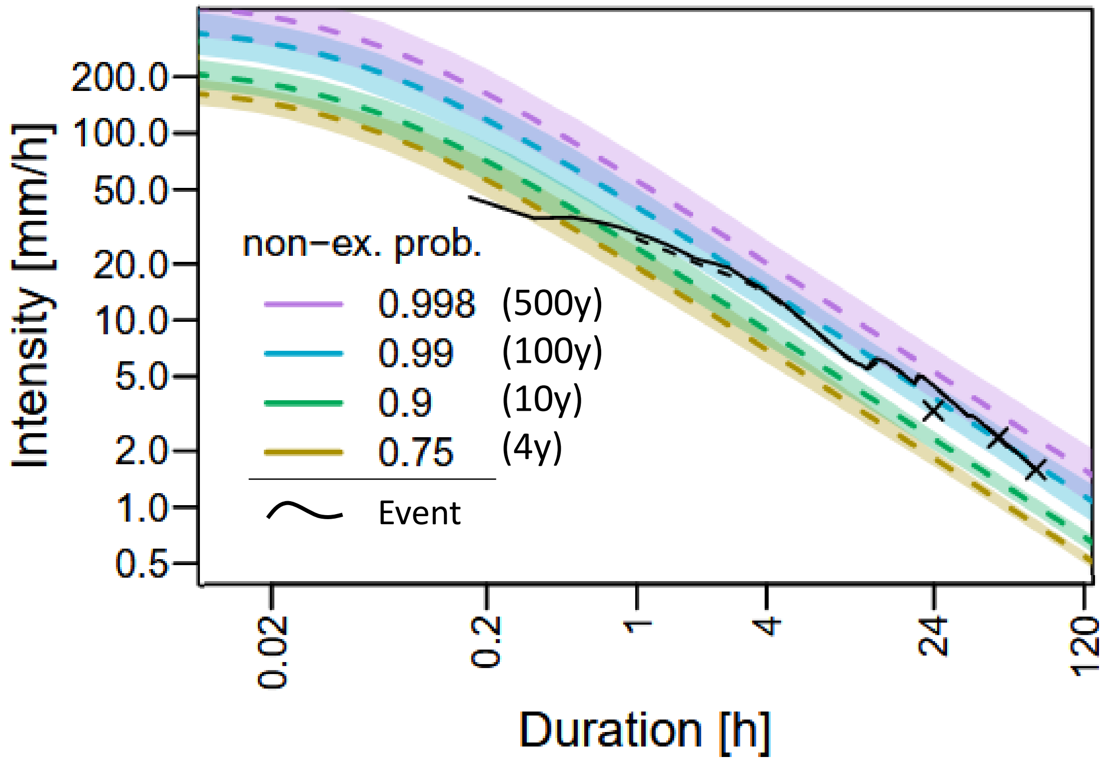
(scale) $\sigma(d)$

(location) $\mu(d)$

(shape) $\xi(d)$

IDF curve

Intensity-duration-frequency



→ Koutsoyiannis et al., 1998
→ Gupta and Waymire, 1990
→ Fauer et al., 2021

Methods

d-GEV

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

(scale) $\sigma(d) = \sigma_0\,(d+\theta)^{-(\eta+\eta_2)} + \tau$

(location) $\mu(d) = \tilde{\mu}\,(\sigma_0\,(d+\theta)^{-\eta} + \tau)$

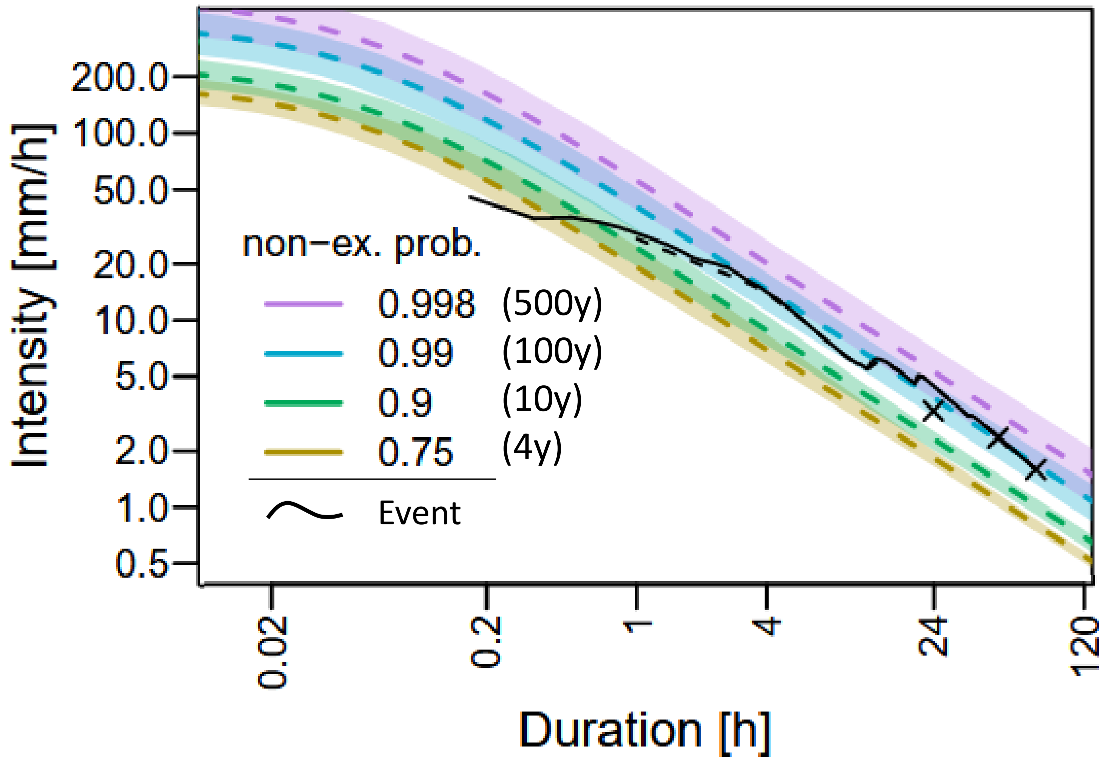
(shape) $\xi(d) = \xi$ [constant]

New d-GEV parameters:

d	**Duration (accumulation period)**
$\tilde{\mu}$	rescaled location
σ_0	normalized scale
θ	duration offset (curvature)
ξ	shape
η_1	duration exponent (slope)
η_2	2nd duration exponent (multiscaling)
τ	intensity offset (flattening)

IDF curve

Intensity-duration-frequency



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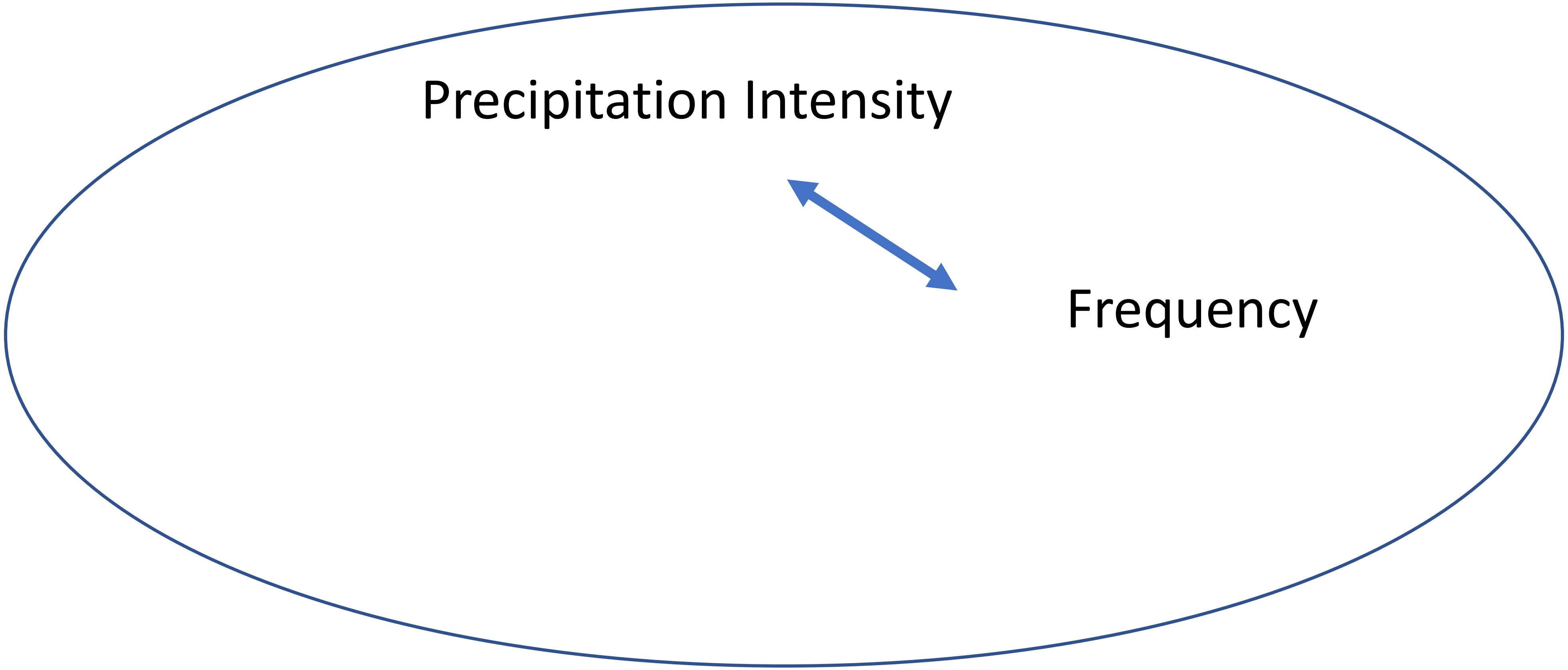
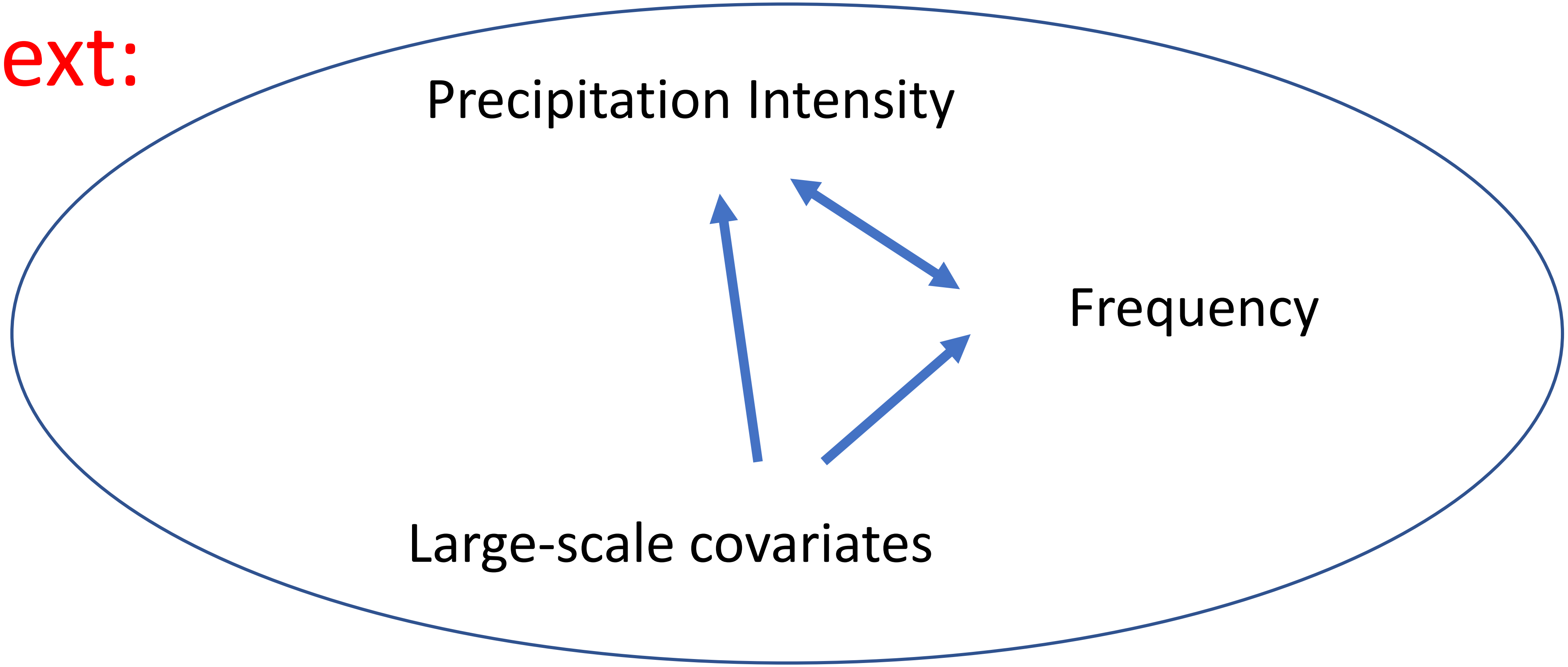


Methods

→ Distribution parameters: function of large-scale variable

Next:



Methods

Distribution parameters: function of large-scale variable

All d-GEV parameters are linear models,
depending on large-scale covariates,
4th order

Example for dependencies of location:

$$\tilde{\mu} = \beta_0 + \beta_1 \, \mathrm{NAO} + \beta_2 \, \mathrm{temperature}^2$$

Methods

Distribution parameters: function of large-scale variable

All d-GEV parameters are linear models,
depending on large-scale covariates,
4th order

Example for dependencies of location:

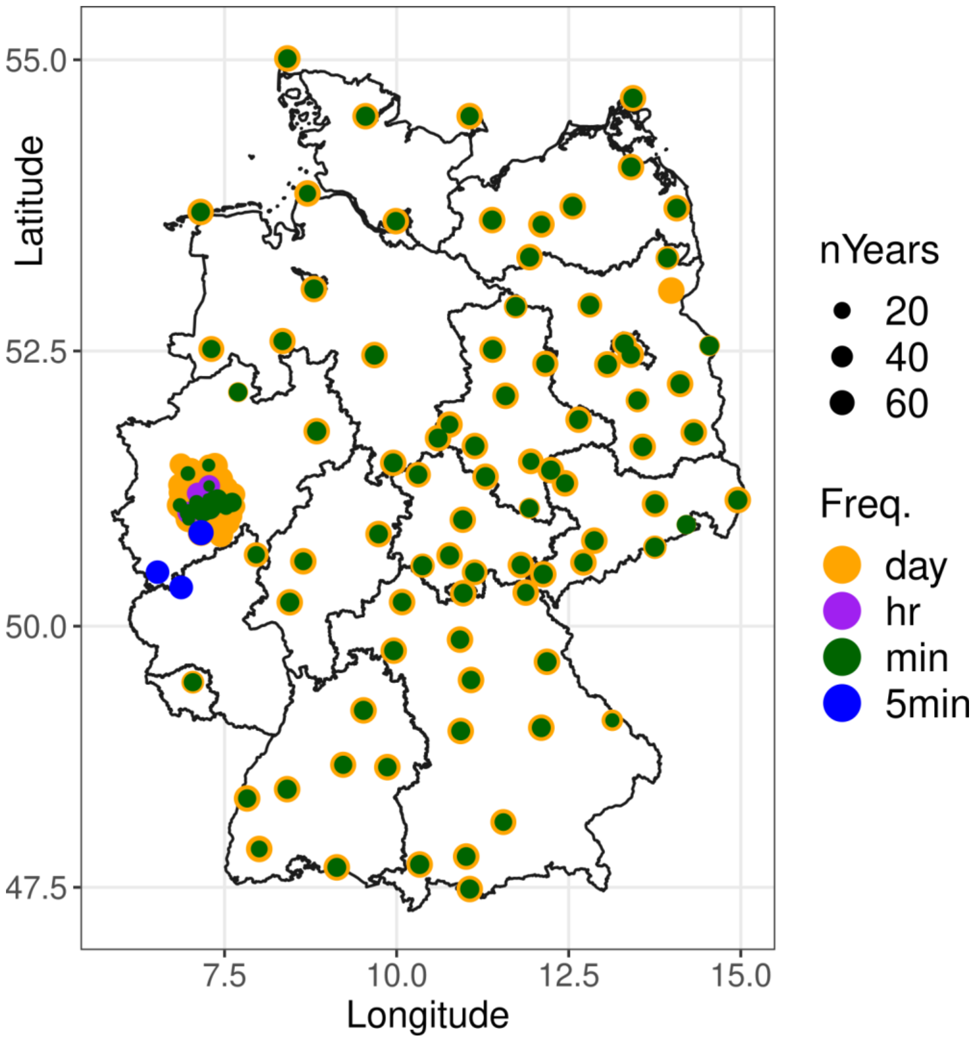
$$\tilde{\mu} = \beta_0 + \beta_1 \, \mathrm{NAO} + \beta_2 \, \mathrm{temperature}^2$$

- Same for all d-GEV parameters
- Stepwise BIC model selection
- Cross-validated (2-fold)

Data

<u>Precipitation</u>

- station-based data



(Fauer, Rust, 2023)

Data

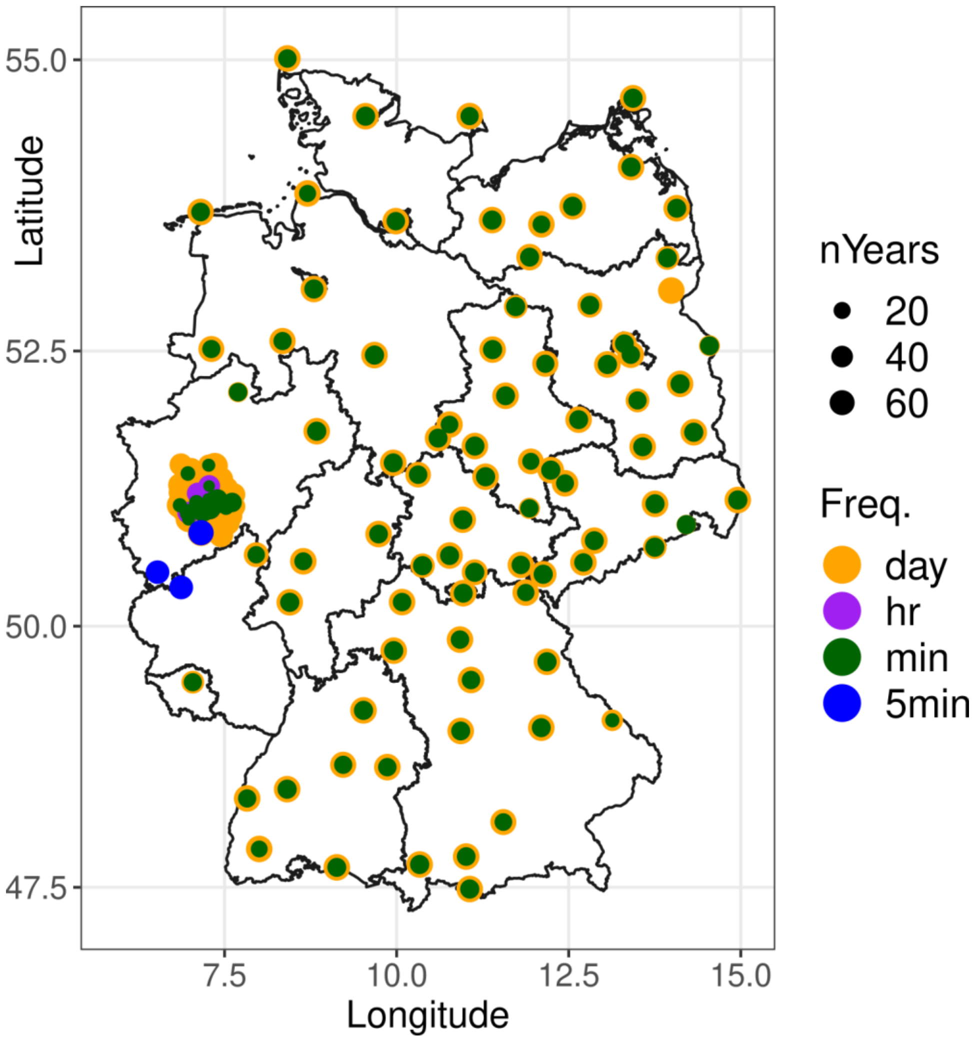
Precipitation

- station-based data

Large-Scale variables

- North Atlantic Oscillation (NOAA)
- Temperature and humidity (ERA5)
- Binary Blocking-Index (BBI) (ERA5)

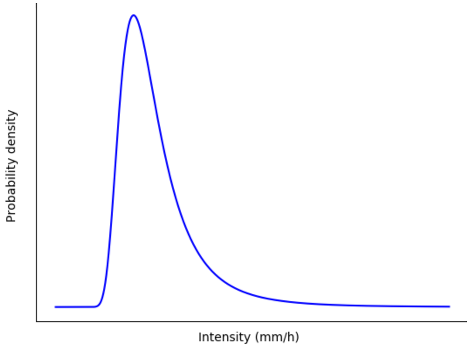
→ all 1950-2015
→ all averaged over month/year



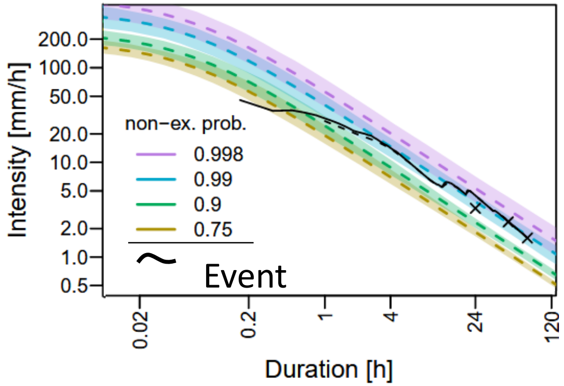
(Fauer, Rust, 2023)

Summary of methods

1. Model distribution of extremes (GEV)



2. Include duration dependence of GEV – parameters (→ d-GEV)



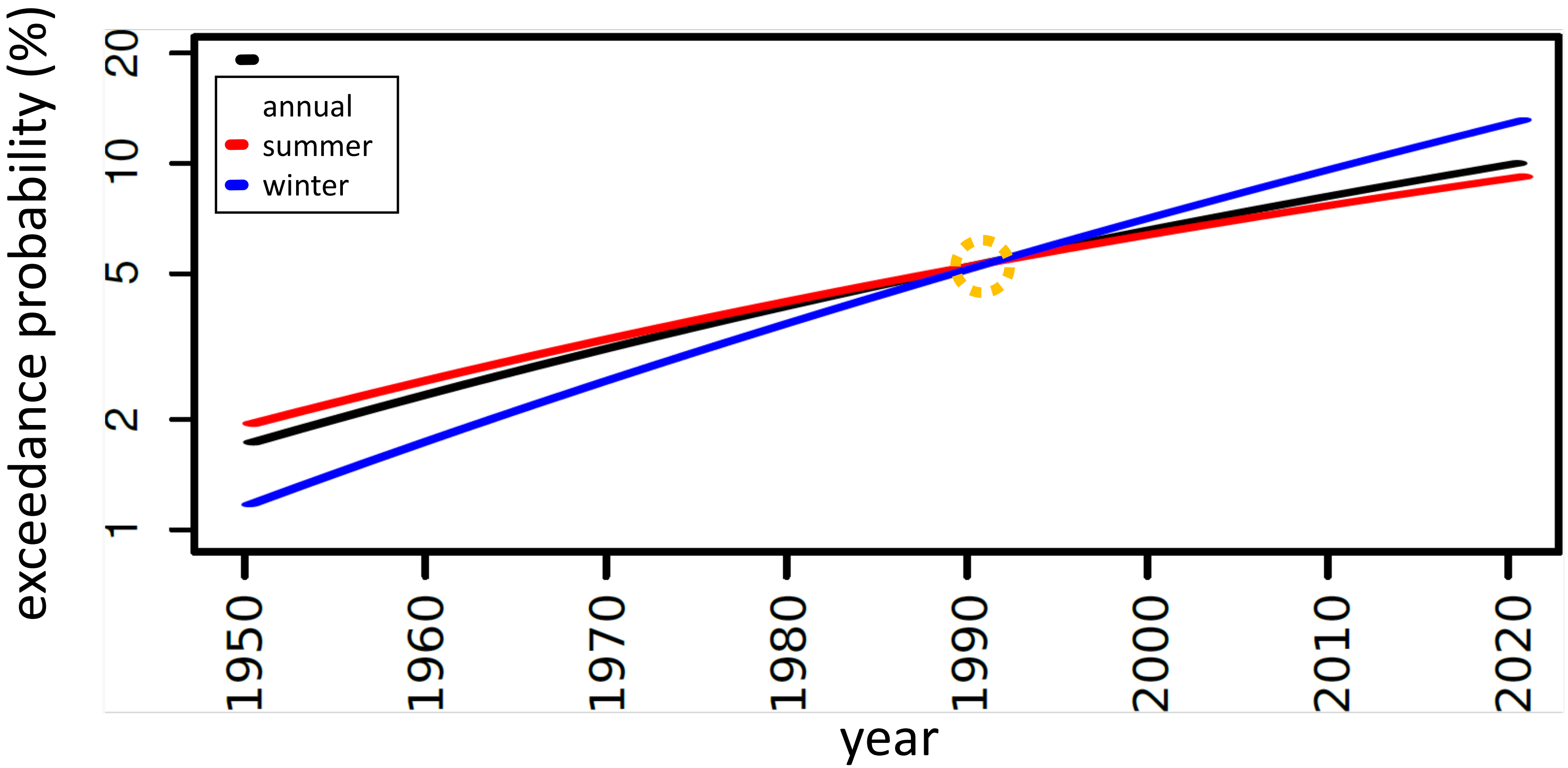
3. Include large-scale dependence of d-GEV parameters

$$\tilde{\mu} = f(NAO, \dots)$$
$$\sigma_0 = f(time, \dots)$$

Results

Large-scale dependencies in the **past**

- define a reference event
- simulate changes of probability ↕ in changing large scale conditions ↔
- other parameters are fixed



Reference event at

- Probability $p = 5\%$
- Year $y = 1990$
- NAO $n = 0$
- Temperature $T = 10°C$
- Blocking $b = 0$
- Humidity $h = 75\%$

One station
Bever-Talsperre

(Fauer, Rust, 2023)

Results

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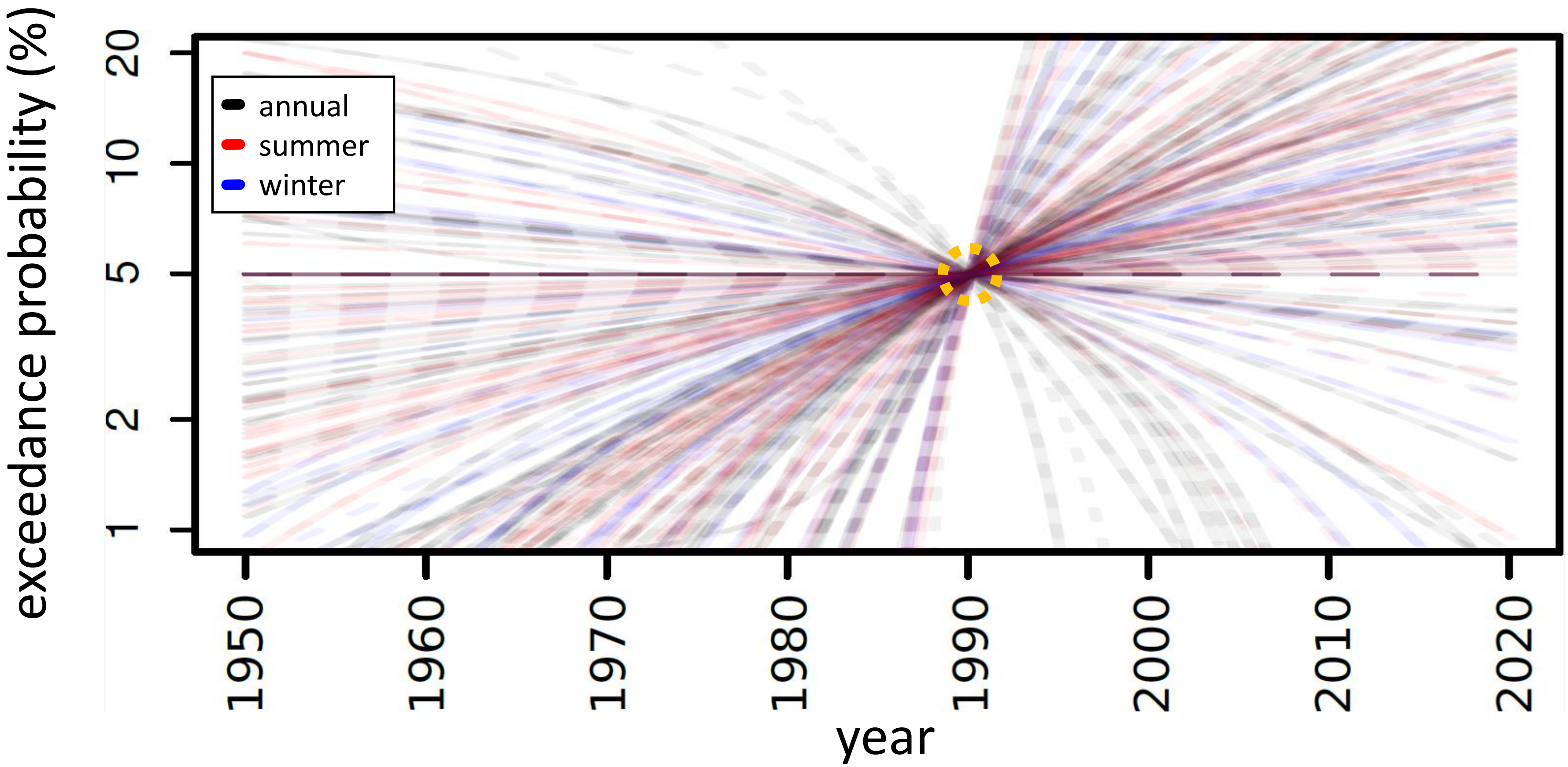

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All Stations

(Fauer, Rust, 2023)

Results

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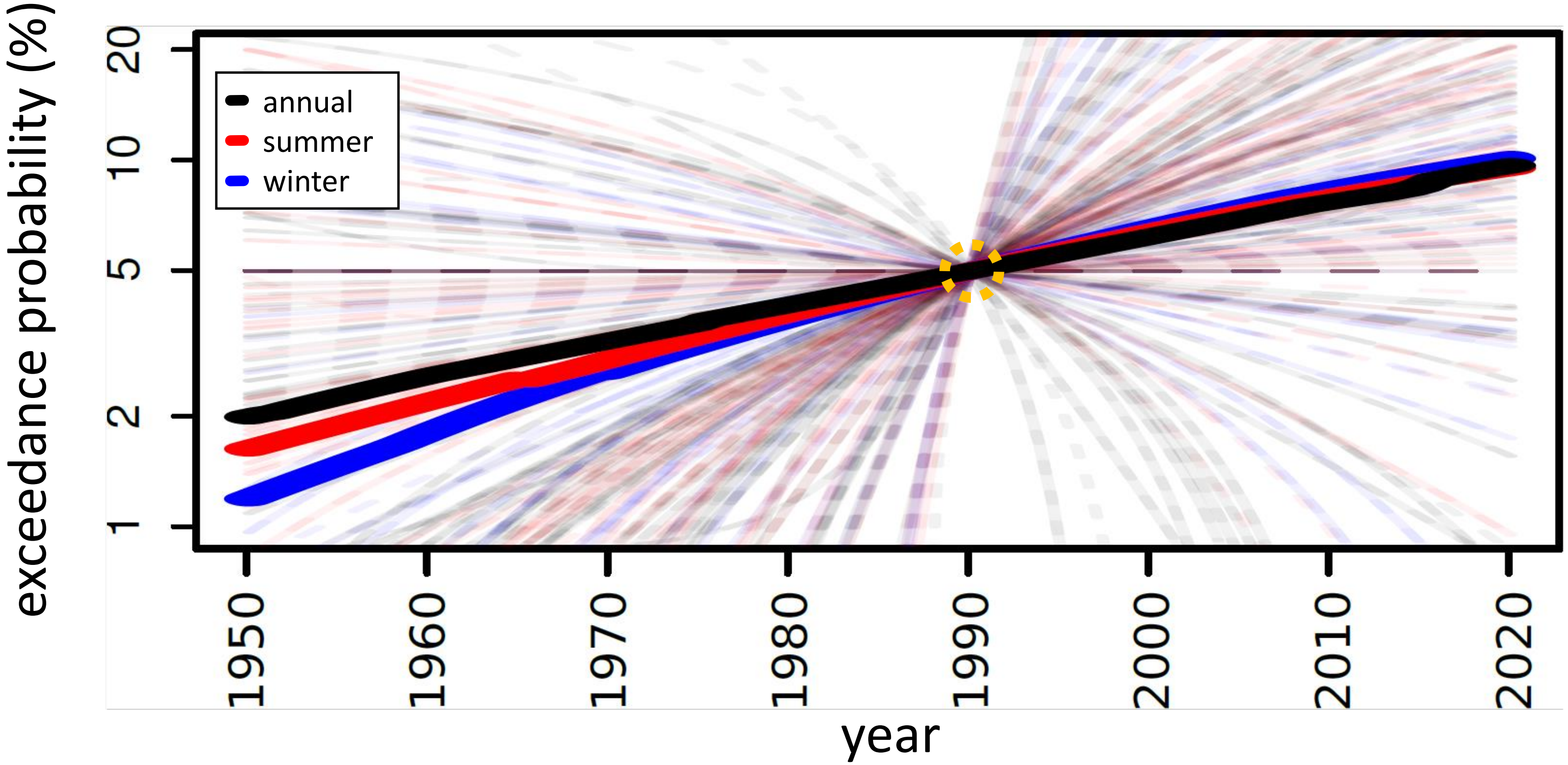

Median over all stations

(Fauer, Rust, 2023)

Results

Large-scale dependencies in the **past**

- define a reference event
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Median over all stations

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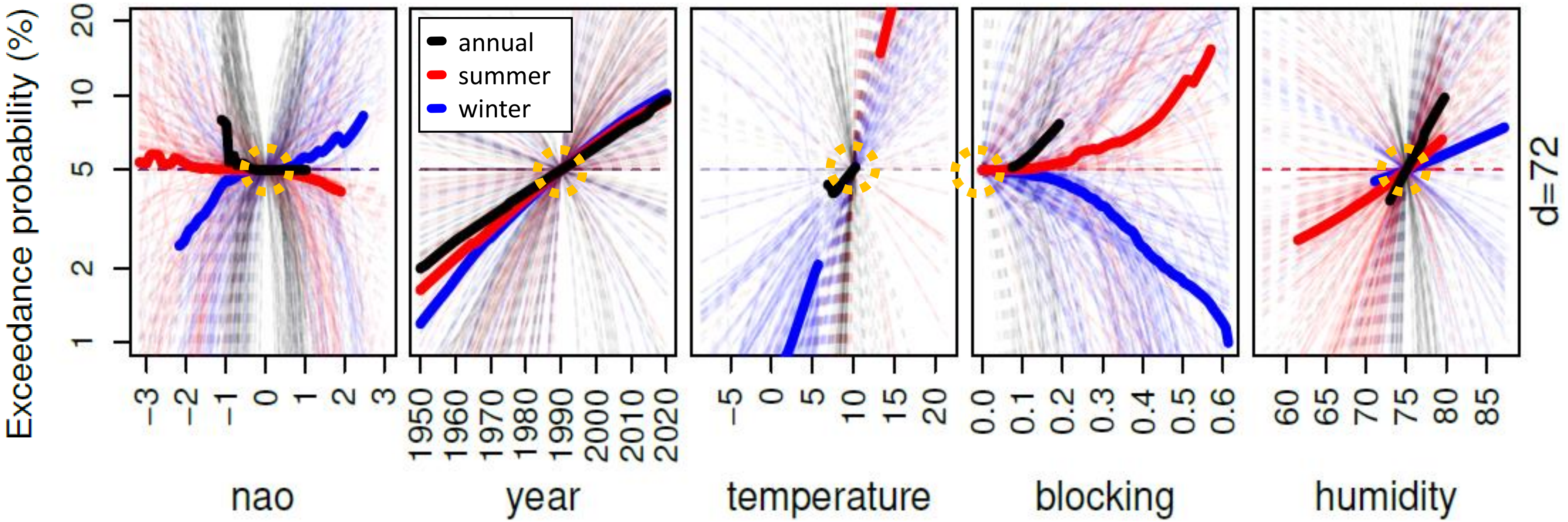
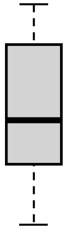


(Fauer, Rust, 2023)

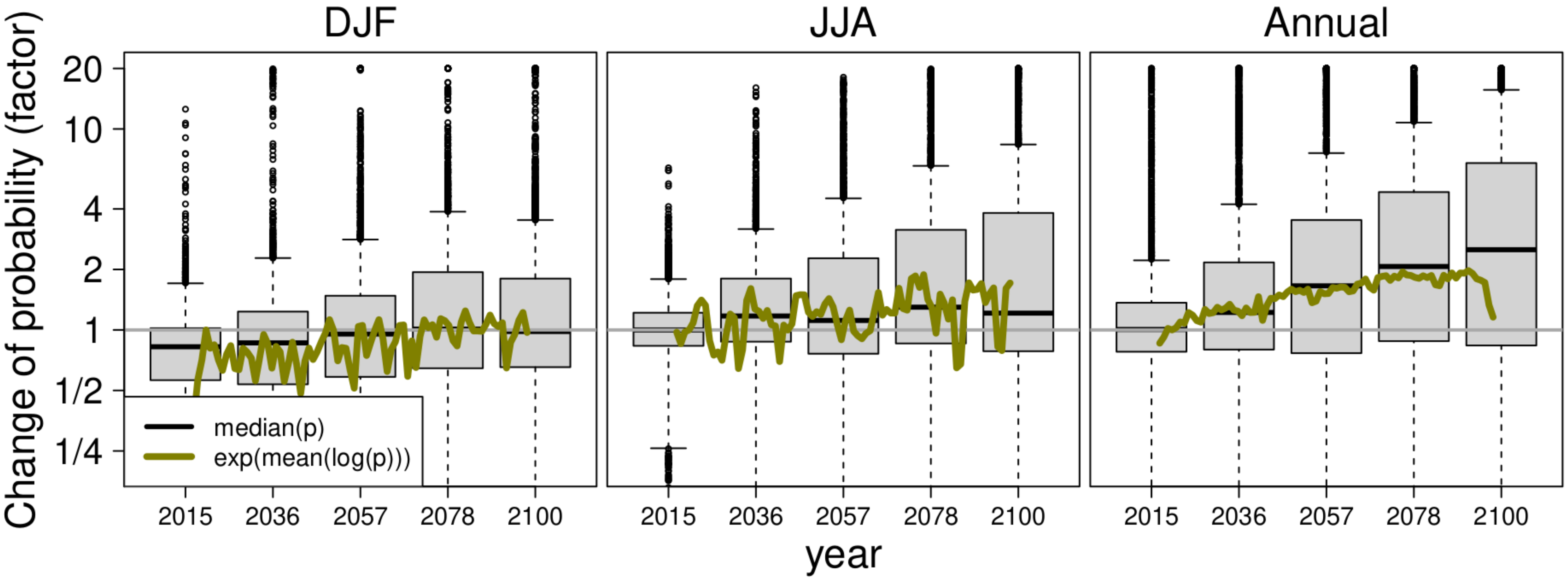
Results

Large-scale dependencies – **Future Projections**

- Simulate changes of probability ↕ in changing large-scale conditions ↔
- Use projections from MPI-ESM for temperature, humidity, blocking, year (5y running mean)



Distribution of 197 stations



Use our R library *IDF* 😊

available on CRAN

```
library(IDF)

# aggregate precip sums
block_maxima = IDF.agg(data, ds)

# estimate d-GEV parameters
fit = gev.d.fit(block_maxima$xdat, block_maxima$ds)

# plot IDF-curves
IDF.plot(ds, gev.d.parameters(fit), lwd=3)
```

- convenient aggregation
- Parallelize processes
- Easy inclusion of covariates
- Extract parameters
- Plot IDF curves
- Customize your plots

Find more information about d-GEV parameters:
Fauer et al, 2021

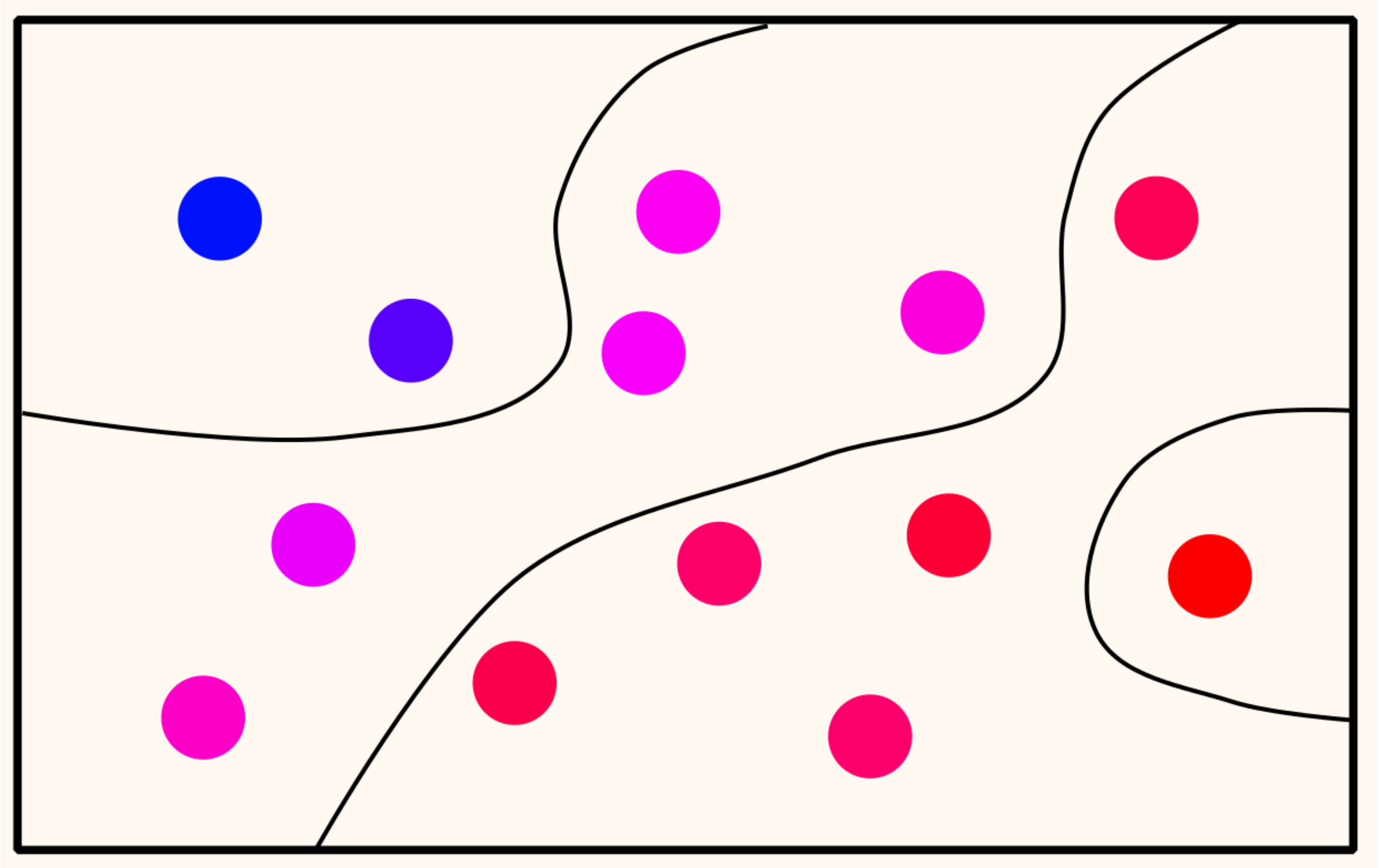
Future Plans - Outlook

Plans

Large-scale dependencies – **Spatial smoothness**

- Exploit smoothness in space for the flexible IDF model based on location covariates

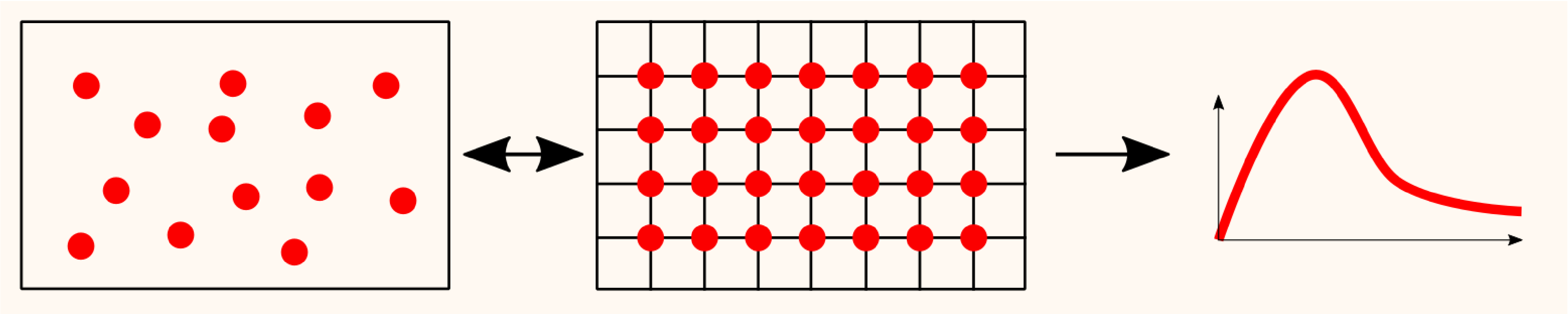
Lat+Lon +
Altitude + slope
as covariates



Plans

Large-scale dependencies – **Gridded Data**

- Develop approaches to combine gridded data sets (high spatial resolution) and station-based data (long time records)



Stations

Grid-based model or reanalysis

Distribution of extremes

Plans

- Identify further meaningful covariates
- Focus on methods to prevent overfitting

Topography

Land cover

Altitude

Slope

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Non-stationary large-scale statistics of precipitation extremes in central Europe

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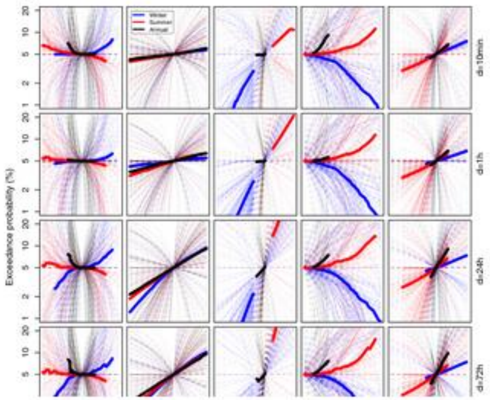
Abstract

Extreme precipitation shows non-stationarity, meaning that its distribution can change with time or other large-scale variables. For a classical frequency-intensity analysis this effect is often neglected. Here, we propose a model including the influence of North Atlantic Oscillation, time, surface temperature and a blocking index. The model features flexibility to use annual maxima as well as seasonal maxima to be fitted in a generalized extreme value setting. To further increase the efficiency of data usage, maxima from different accumulation durations are aggregated so that information for extremes on different time scales can be provided. Our model is trained to individual station data with temporal resolutions ranging from one minute to one day across Germany. Models are chosen with a stepwise BIC model selection and verified with a cross-validated quantile skill index. The verification shows that the new model performs better than a reference model without large-scale information. Also, the new model enables insights into the

Fig. 6



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Thank you for Listening

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