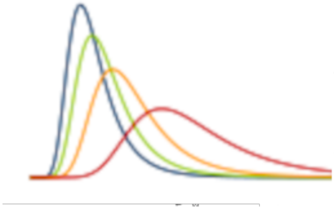
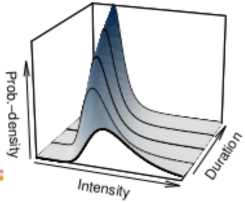
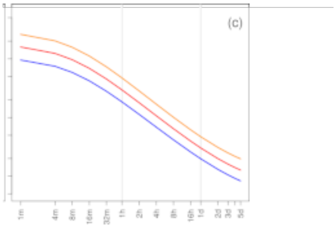






Intensity Duration Frequeny Relations

Henning Rust, Felix Fauer, Jana Ulrich, Oscar Jurado
Institut für Meteorologie, Freie Universität Berlin

Roscoff, 30.030.2025


Urban Drainage Design determine capacity of drainage system or components

FREIE UNIVERSITÄT BERLIN

Urban Drainage Design determine capacity of drainage system or components

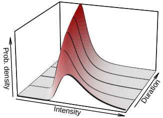
Flood Risk Assessment due to rainfall, knowing exceedance probabilities

Urban Drainage Design determine capacity of drainage system or components

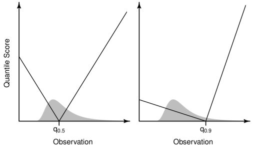
Flood Risk Assessment due to rainfall, knowing exceedance probabilities

Agricultural Planning design drainage/irrigation systems, protecting crops

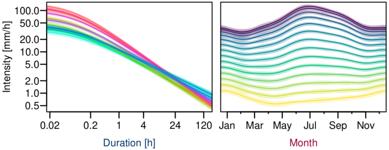
Overview



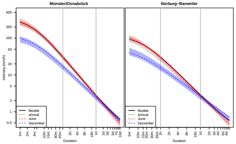
Duration-dep. GEV



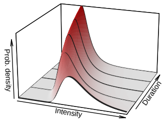
Quantile Score



Seasonal IDF



Flexible IDF

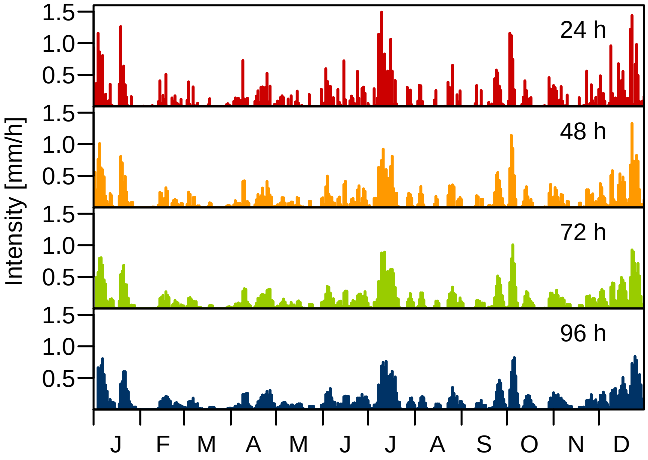


Duration-dependent GEV

Extreme values for different durations

- Daily data
- Calculate precipitation intensities I for different durations d

$$I(t,d) = \frac{1}{d} \sum_{t'=t-d}^{t} pr(t')$$

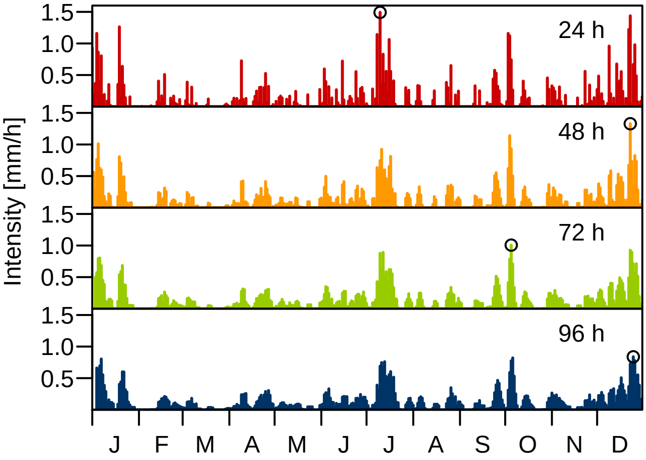


- Daily data
- Calculate precipitation intensities I for different durations d

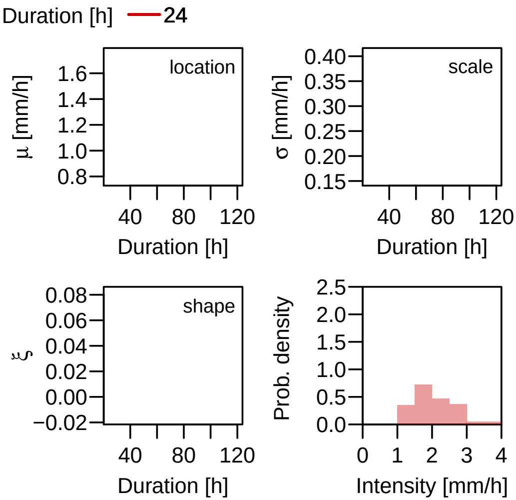
$$I(t,d) = \frac{1}{d}\sum_{t'=t-d}^{t} pr(t')$$

- Extreme values:
- Block maxima approach

→ e.g. Annual maxima for different durations



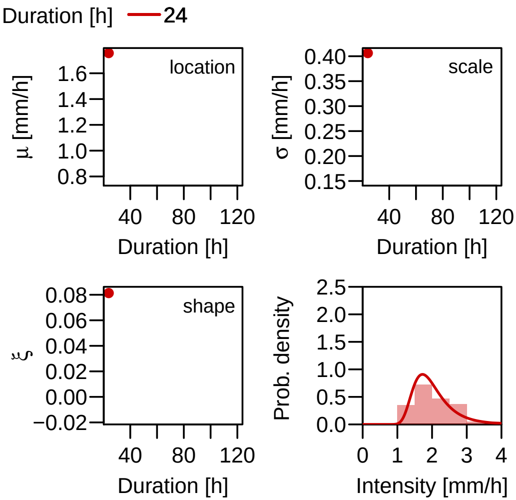
Estimate GEV for different durations



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

- GEV: modeling distribution of annual intensity maxima
- Separately for each duration

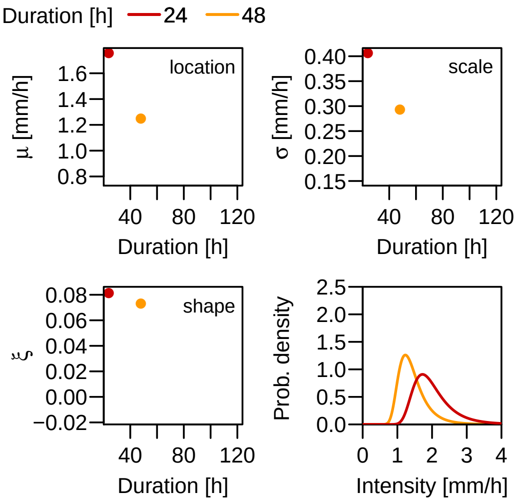
Estimate GEV for different durations



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

- GEV: modeling distribution of annual intensity maxima
- Separately for each duration

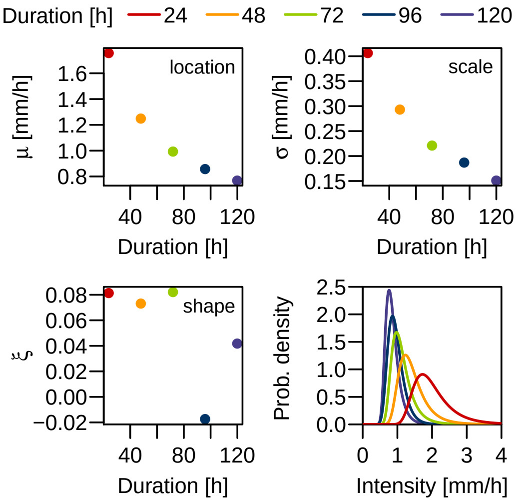
Estimate GEV for different durations



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

- GEV: modeling distribution of annual intensity maxima
- Separately for each duration

Estimate GEV for different durations

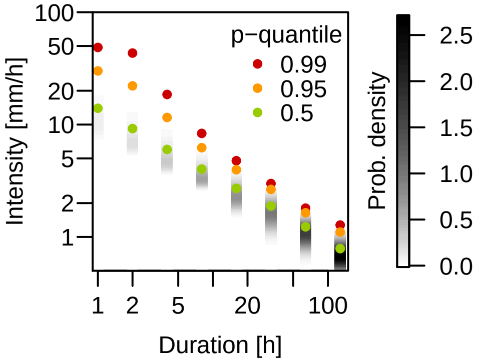


$$G(I) = \exp\left\{-\left[1+\xi\left(\frac{I-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

- GEV: modeling distribution of annual intensity maxima
- Separately for each duration

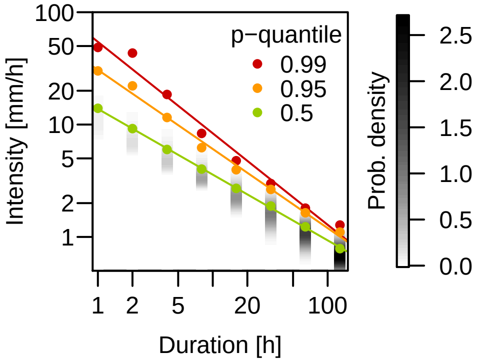
Typical approach (Engineers, DWD)

- 2 separate statistical models
  1. EVD (GEV) for different durations



Typical approach (Engineers, DWD)

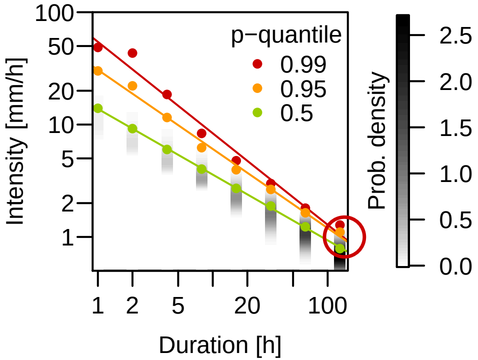
- 2 separate statistical models
  1. EVD (GEV) for different durations
  2. quantiles smooth function of duration



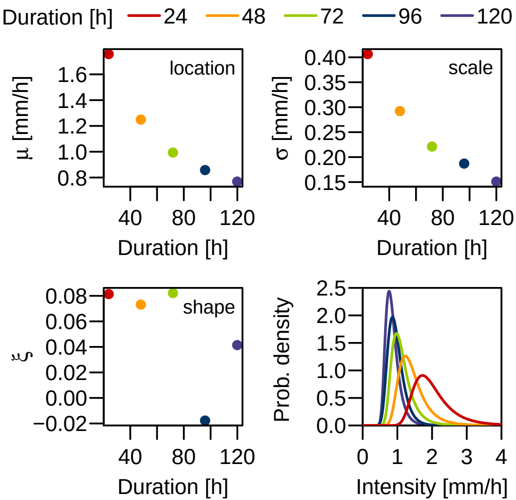
Typical approach (Engineers, DWD)

- 2 separate statistical models
  1. EVD (GEV) for different durations
  2. quantiles smooth function of duration
- crossing of quantiles

→ **Inconsistent**



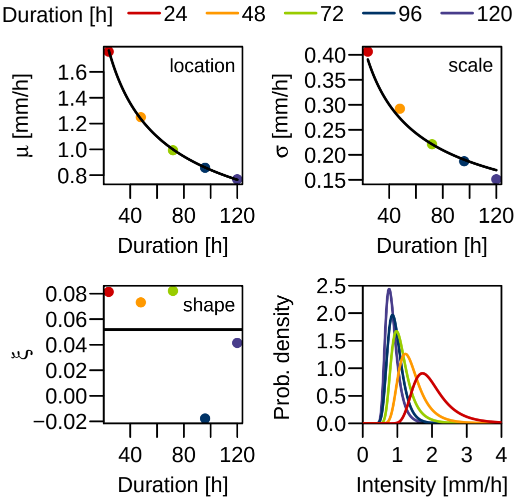
Duration-dependent GEV



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

- Idea: model dependence of GEV parameters on duration

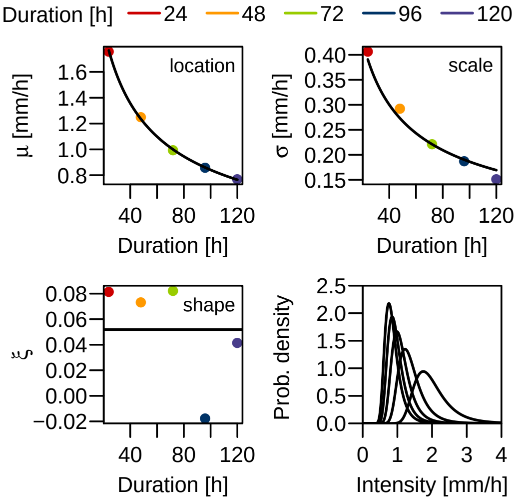
Duration-dependent GEV



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

- Idea: model dependence of GEV parameters on duration

Duration-dependent GEV



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

- Idea: model dependence of GEV parameters on duration

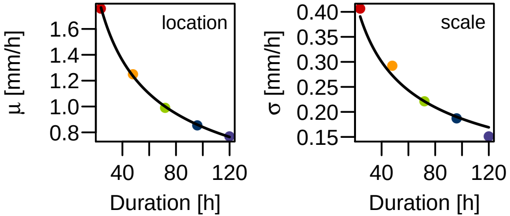
→ **Model all durations at once**

Duration-dependent GEV

- Assumptions for d-dependence of μ, σ, ξ by Koutsoyiannis et al., 1998, J. Hydrol., 206:

Duration-dependent GEV

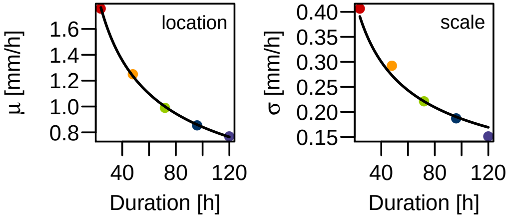
- Assumptions for d-dependence of μ, σ, ξ by Koutsoyiannis et al., 1998, J. Hydrol., 206:



- location and scale show similar behavior

Duration-dependent GEV

- Assumptions for d-dependence of μ, σ, ξ by Koutsoyiannis et al., 1998, J. Hydrol., 206:

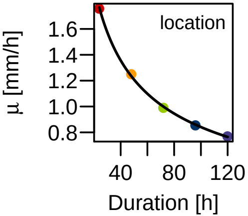


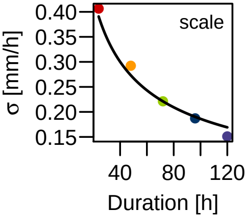
- location and scale show similar behavior
- use 2 additional parameters: θ and η

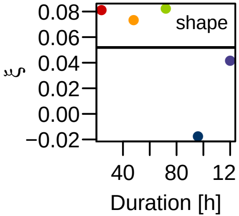
$$\mu(d) = \tilde{\mu}\,\sigma(d)$$

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

- Assumptions for d-dependence of μ, σ, ξ by Koutsoyiannis et al., 1998, J. Hydrol., 206:







- location and scale show similar behavior
- use 2 additional parameters: θ and η

$$\mu(d) = \tilde{\mu}\,\sigma(d)$$

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

- shape: no obvious dependence

$$\xi \neq f(d)$$

Duration-Dependent GEV (d-GEV)

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

Duration-Dependent GEV (d-GEV)

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

→ assumptions for parameters [1]

$$\begin{aligned}
\mu(d) &= \tilde{\mu}\cdot\sigma(d)\\
\sigma(d) &= \sigma_0\cdot(d+\theta)^{-\eta}\\
\xi(d) &= \text{const.}
\end{aligned}$$

Duration-Dependent GEV (d-GEV)

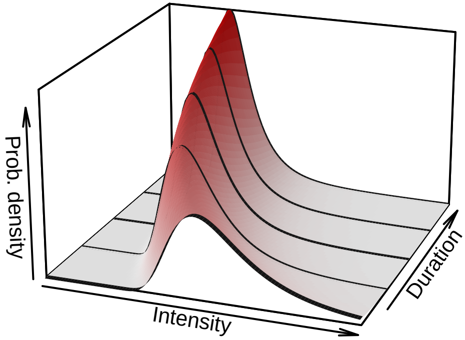
$$G(z) = \exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

→ assumptions for parameters [1]

$$\begin{aligned} \mu(d) &= \tilde{\mu}\cdot\sigma(d) \\ \sigma(d) &= \sigma_0\cdot(d+\theta)^{-\eta} \\ \xi(d) &= \text{const.} \end{aligned}$$

→ one d-GEV for all durations:

$$G(z,d) = \exp\left\{-\left[1+\xi\left(\frac{z}{\sigma_0\cdot(d+\theta)^{-\eta}}-\tilde{\mu}\right)\right]^{-1/\xi}\right\}$$



[1] Koutsoyiannis et al. *J. Hydrol.* 1998, 206:118–135.

What we expect (pros)

- more efficient use of the data
  - → reduced uncertainty
  - → more complexity possible for modelling
    - seasonal cycle
    - spatial variability
    - climate change
- consistency (no quantile crossing)

Consistent and parsimonious IDF curves

What we expect (pros)

- more efficient use of the data
  - → reduced uncertainty
  - → more complexity possible for modelling
    - seasonal cycle
    - spatial variability
    - climate change
- consistency (no quantile crossing)

What we expect (cons)

- dependence between durations ⟶ problems
  → Jurado et al., *Water* 2020, 12(12), 3314; `https://doi.org/10.3390/w12123314`

Summary

- Model intensity maxima for all durations simultaneously → **d-GEV**

→ one model with consistent quantiles (instead of 2)

- d-GEV (+ generalized linear modelling of parameters) implemented in **R-Package 'IDF'**

Summary

- Model intensity maxima for all durations simultaneously → **d-GEV**

→ one model with consistent quantiles (instead of 2)

- d-GEV (+ generalized linear modelling of parameters) implemented in **R-Package ’IDF’**

Further Questions

- Does this improve the quantile estimation?
- Useful beyond consistent quantile estimation?

Summary and Further Questions

Summary

- Model intensity maxima for all durations simultaneously → **d-GEV**

→ one model with consistent quantiles (instead of 2)

- d-GEV (+ generalized linear modelling of parameters) implemented in **R-Package 'IDF'**

Further Questions

- Does this improve the quantile estimation?
  → **compare to individual durations (QVS)**

- Useful beyond consistent quantile estimation?

Summary and Further Questions

Summary

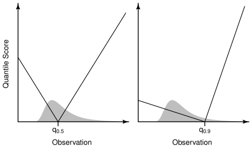
- Model intensity maxima for all durations simultaneously → **d-GEV**

→ one model with consistent quantiles (instead of 2)

- d-GEV (+ generalized linear modelling of parameters) implemented in **R-Package 'IDF'**

Further Questions

- Does this improve the quantile estimation?
  → **compare to individual durations (QVS)**
- Useful beyond consistent quantile estimation?
  → **seasonal and spatial covariates**



Quantile verification score

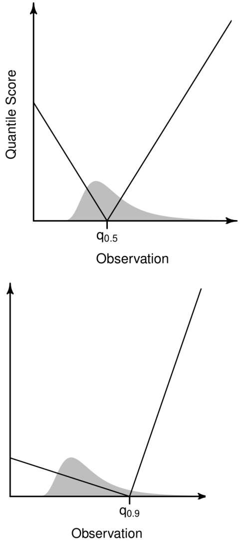
Quantile Verification Score

For exceedance probability p

$$\mathrm{QS}(p) = \frac{1}{N}\sum_{n=1}^{N} \rho_p(o_n - q_p),$$

$$\rho_p(u) = \begin{cases} pu & , u \geq 0 \\ (p-1)u & , u < 0. \end{cases}$$

$\mathrm{QS} \geq 0$, negatively oriented, $QS(p)_{\mathrm{pef}} = 0$



Quantile Skill Score

$$\text{Skill Score} = \frac{\text{QS}(p) - \text{QS}(p)_{\text{ref}}}{\text{QS}(p)_{\text{perf}} - \text{QS}(p)_{\text{ref}}}$$

with $QS(p)_{\text{perf}} = 0$

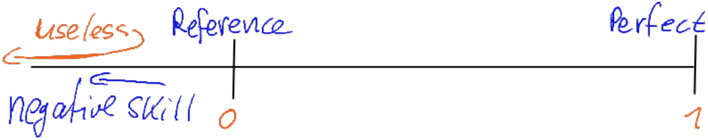
$$\text{Skill Score} = \frac{\text{QS}(p) - \text{QS}(p)_{\text{ref}}}{0 - \text{QS}(p)_{\text{ref}}} = 1 - \frac{\text{QS}(p)}{\text{QS}(p)_{\text{ref}}}$$

Quantile Skill Score

$$\text{Skill Score} = \frac{QS(p) - QS(p)_{\text{ref}}}{QS(p)_{\text{perf}} - QS(p)_{\text{ref}}}$$

with $QS(p)_{\text{perf}} = 0$

$$\text{Skill Score} = \frac{QS(p) - QS(p)_{\text{ref}}}{0 - QS(p)_{\text{ref}}} = 1 - \frac{QS(p)}{QS(p)_{\text{ref}}}$$



Model improvement over reference

$$\mathrm{QSS}^{M}_{s,d}(p) = 1 - \frac{\mathrm{QS}^{M}_{s,d}(p)}{\mathrm{QS}^{R}_{s,d}(p)}$$

Quantile Skill Index

Model improvement over reference

$$\mathrm{QSS}^{M}_{s,d}(p) = 1 - \frac{\mathrm{QS}^{M}_{s,d}(p)}{\mathrm{QS}^{R}_{s,d}(p)}$$

Loss – Referenz compared to model

$$\mathrm{QSS}^{R}_{s,d}(p) = 1 - \frac{\mathrm{QS}^{R}_{s,d}(p)}{\mathrm{QS}^{M}_{s,d}(p)}$$

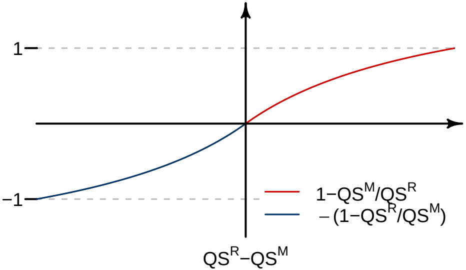
Quantile Skill Index

Model improvement over reference

$$\mathrm{QSS}^{M}_{s,d}(p) = 1 - \frac{\mathrm{QS}^{M}_{s,d}(p)}{\mathrm{QS}^{R}_{s,d}(p)}$$

Loss – Referenz compared to model

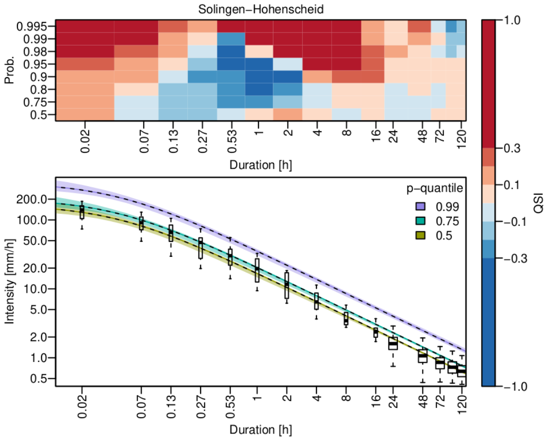
$$\mathrm{QSS}^{R}_{s,d}(p) = 1 - \frac{\mathrm{QS}^{R}_{s,d}(p)}{\mathrm{QS}^{M}_{s,d}(p)}$$



"Quantile Skill Index combine both informations:

$$\mathrm{QSI}_{s,d}(p) = \begin{cases} \mathrm{QSS}^{M}_{s,d}(p) & , \mathrm{QS}^{M}_{s,d}(p) \leq \mathrm{QS}^{R}_{s,d}(p) \\ \mathrm{QSS}^{R}_{s,d}(p) & , \mathrm{QS}^{M}_{s,d}(p) > \mathrm{QS}^{R}_{s,d}(p) \end{cases}$$

Example: d-GEV with spatial covariates vs. single station individual durations



Solingen-Hohenscheid, Wupperverband, d-GEV with spatial covariates.

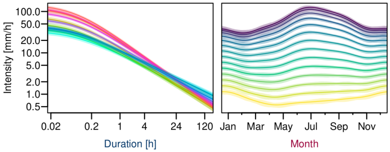
QSI vs. individual durations GEV for single station

Summary

- Quantiles are the goal, detailled verification for
  - all probabilities / return periods
  - durations
- use in cross validation setting

Reference

Estimating IDF curves consistently over durations with spatial covariates.
J. Ulrich, O. Jurado, M. Peter, M. Scheibel and H. Rust
Water, 12(11), 3119
`https://www.mdpi.com/2073-4441/12/11/3119`



Seasonal IDF

Monthly Maxima and Seasonally Varying Parameters

- Model monthly maxima for range of durations using d-GEV

$$G(z, d;\ \tilde{\mu}\quad, \sigma_0\quad, \xi\quad, \theta\quad, \eta\quad)$$

Monthly Maxima and Seasonally Varying Parameters

- Model monthly maxima for range of durations using d-GEV with monthly covariates[1]

$$G(z, d;\ \tilde{\mu}(m),\ \sigma_0(m),\ \xi(m),\ \theta(m),\ \eta(m)\ )$$

[1] e.g. Fischer et al. *Meteorol. Z.* 2018, 27:3–13

Monthly Maxima and Seasonally Varying Parameters

- Model monthly maxima for range of durations using d-GEV with monthly covariates[1]

$$G(z, d;\ \tilde{\mu}(m),\ \sigma_0(m),\ \xi(m),\ \theta(m),\ \eta(m)\ )$$

- Sum of trigonometric functions for all parameters $\phi \in \{\tilde{\mu}, \sigma_0, \xi, \theta, \eta\}$:

$$\phi(m) = \phi_0 + \sum_{j=1}^{J} \left[\beta_j^{\phi} \sin(j\omega m) + \gamma_j^{\phi} \cos(j\omega m)\right],$$

with $\omega = 2\pi/12$
and m: month of the year

[1] e.g. Fischer et al. *Meteorol. Z.* 2018, 27:3–13

Monthly Maxima and Seasonally Varying Parameters

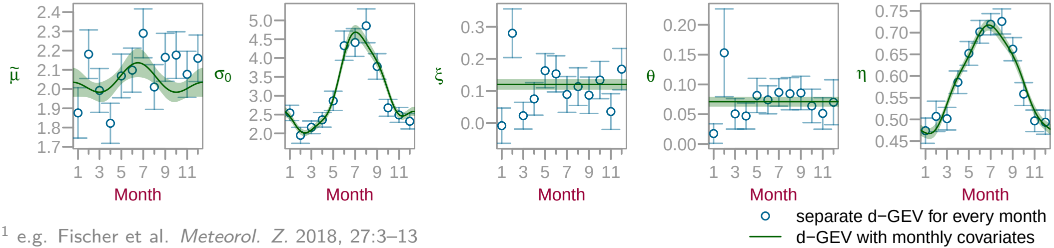
- Model monthly maxima for range of durations using d-GEV with monthly covariates[1]

$$G(z, d;\ \tilde{\mu}(m),\ \sigma_0(m),\ \xi(m),\ \theta(m),\ \eta(m)\ )$$

- Sum of trigonometric functions for all parameters $\phi \in \{\tilde{\mu}, \sigma_0, \xi, \theta, \eta\}$:

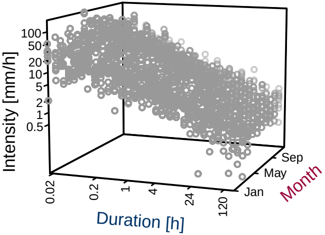
$$\phi(m) = \phi_0 + \sum_{j=1}^{J} \left[\beta_j^{\phi} \sin(j\omega m) + \gamma_j^{\phi} \cos(j\omega m) \right],$$

with $\omega = 2\pi/12$
and m: month of the year



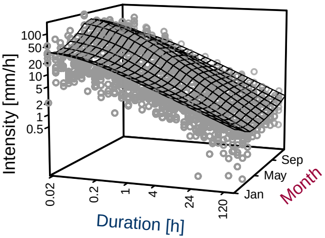
[1] e.g. Fischer et al. *Meteorol. Z.* 2018, 27:3–13

How does the IDF relationship vary throughout the year?



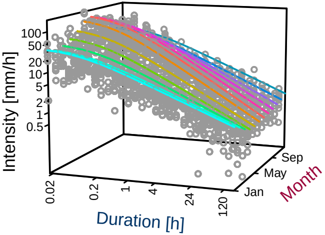
- Example station Bever-Talsperre

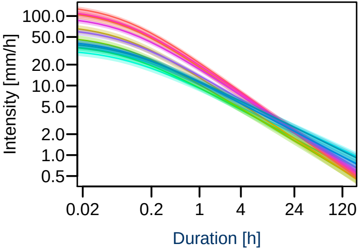
How does the IDF relationship vary throughout the year?



- Example station Bever-Talsperre
- Estimated 0.9-quantile

How does the IDF relationship vary throughout the year?

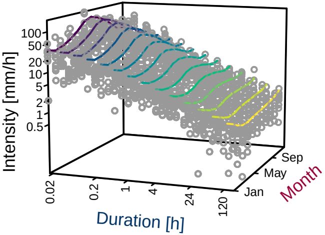




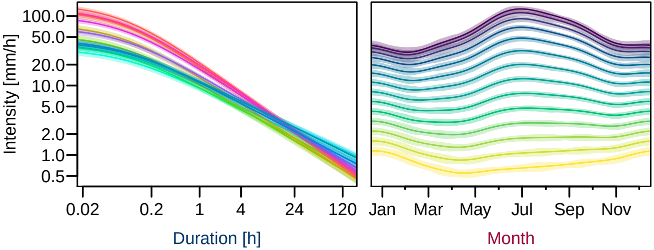
- Example station Bever-Talsperre
- Estimated 0.9-quantile
- For each month

- IDF-curves
  - more steep in summer months

How does the IDF relationship vary throughout the year?



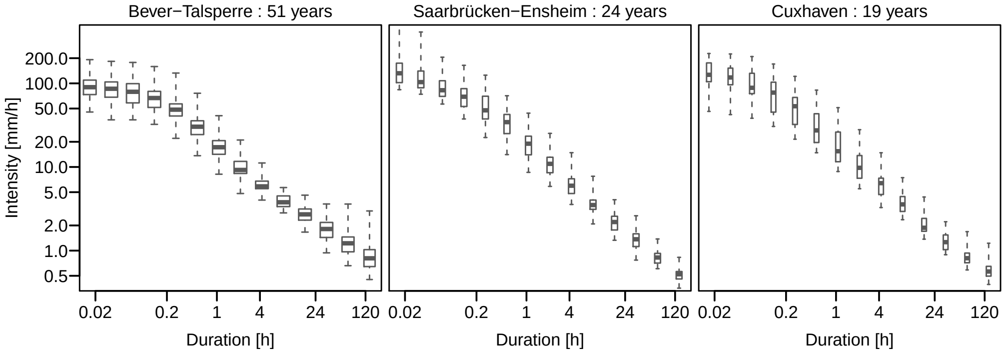
- Example station Bever-Talsperre
- Estimated 0.9-quantile
- For each month
- For each aggregation level



- IDF-curves
  - more steep in summer months
- Intensity maxima
  - short durations: summer
  - long durations: autumn/ winter

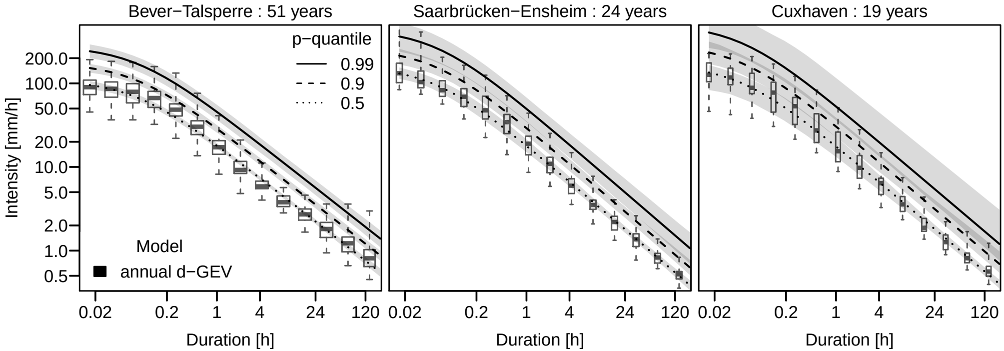
Can we improve annual IDF curves by accounting for seasonality?

- For 3 different stations,
  i.e. different length of time series:



Can we improve annual IDF curves by accounting for seasonality?

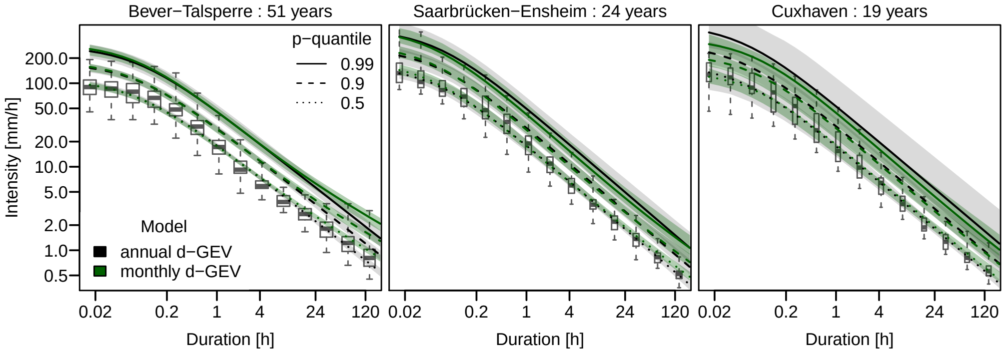
- For 3 different stations,
  i.e. different length of time series:
- Estimate annual IDF curves based on
  - Annual maxima



Can we improve annual IDF curves by accounting for seasonality?

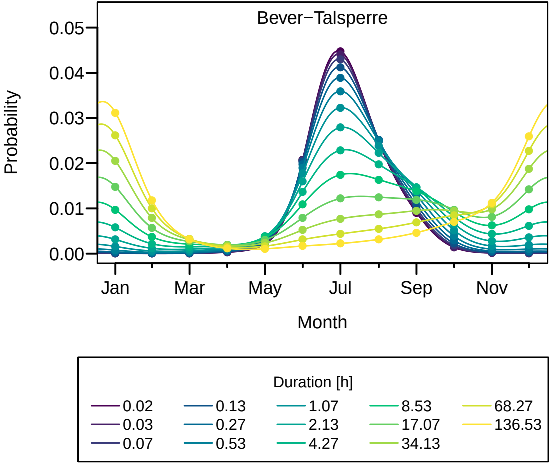
- For 3 different stations,
  i.e. different length of time series:
- Estimate annual IDF curves based on
  - Annual maxima
  - Monthly maxima

- Reduced uncertainties
- Less restricted dependence on duration



When in the year do annual maxima occur?

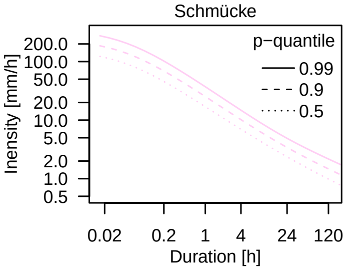
- Probability that annual 0.9-quantile is exceeded in certain month



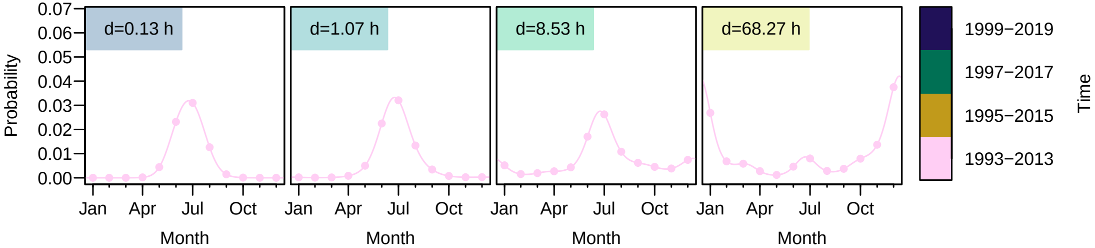
- Maximum probability shifts
  - from summer for short durations (convective events)
  - to winter for long durations (frontal events)
- Seasonality of long-lasting events depends on location

Outlook

How do Intensity and seasonality change over time?

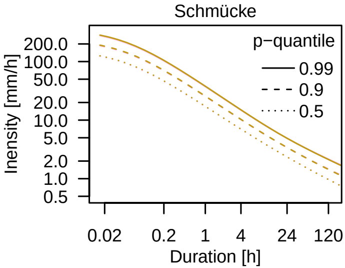


Moving 20 year time window

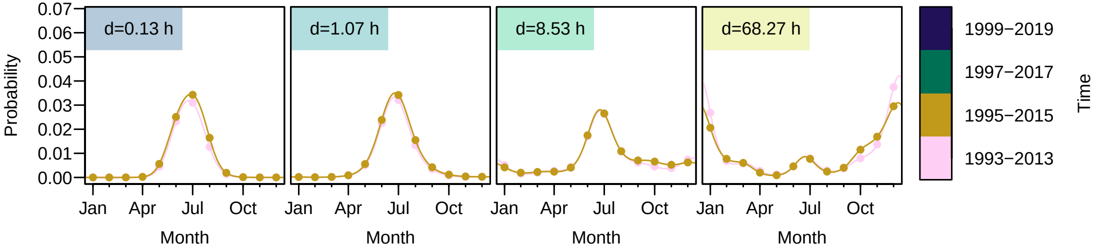


Outlook

How do Intensity and seasonality change over time?

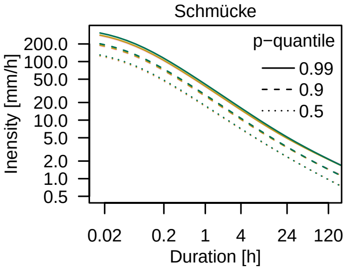


Moving 20 year time window

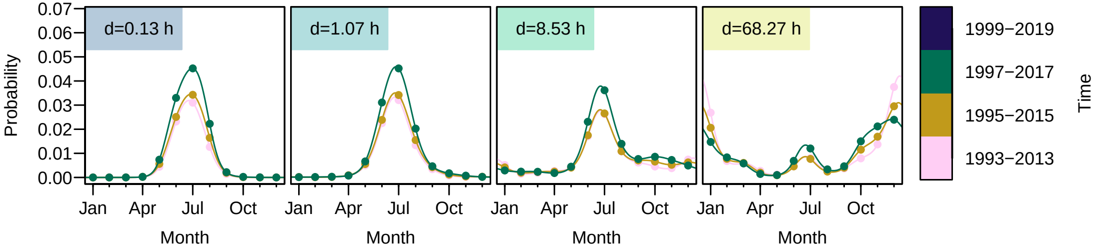


Outlook

How do Intensity and seasonality change over time?

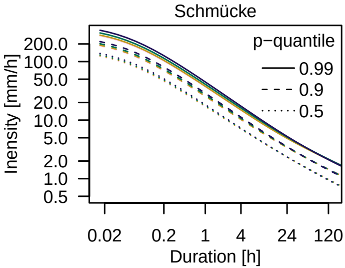


Moving 20 year time window



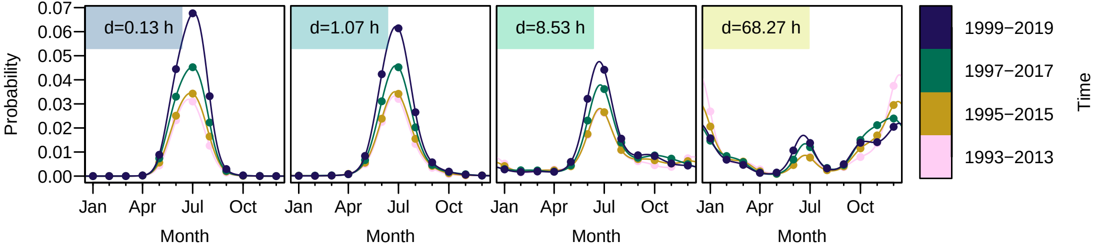
Outlook

How do Intensity and seasonality change over time?



Moving 20 year time window

- short durations: increasing intensities
- long durations: changes in seasonality



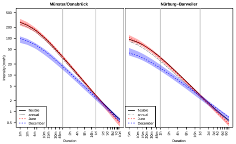
Summary and Reference

Summary

- reduced uncertainty ($\leftarrow$ esp. short series)
- increase flexibility ($\leftarrow$ esp. long series)

Reference

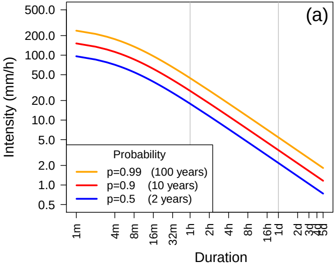
Modeling seasonal variations of extreme rainfall
on different time scales in Germany
J. Ulrich, F. Fauer, H. Rust
Hydrology and Earth System Sciences 25.12 (2021): 6133-6149
`https://hess.copernicus.org/articles/25/6133/2021/`



Flexible IDF

Add flexibility to d-GEV

„curvature“(d-GEV)



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

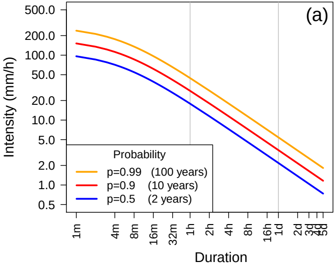
$$\mu(d) = \tilde{\mu}\left(\sigma_0 \left(d + \theta\right)^{-\eta}\right)$$

$$\sigma(d) = \sigma_0 \left(d + \theta\right)^{-\eta}$$

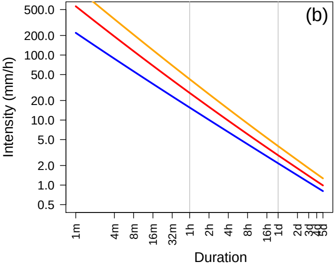
$$\xi = \xi_0$$

Add flexibility to d-GEV

„curvature“(d-GEV)



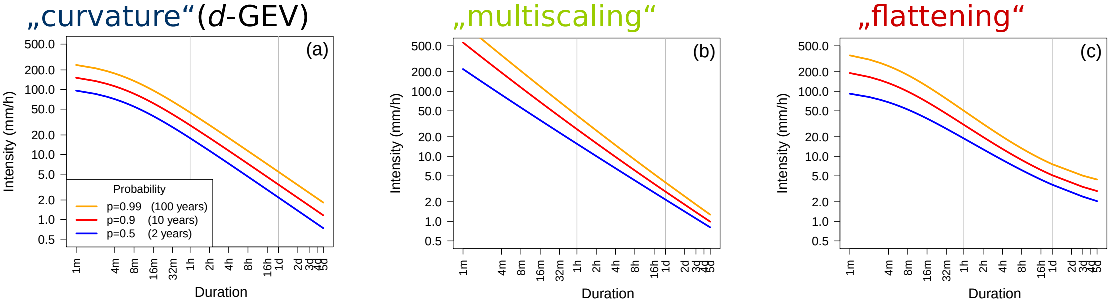
„multiscaling“



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

$$\mu(d) = \tilde{\mu}\left(\sigma_0\left(d+\theta\right)^{-\eta}\right)$$
$$\sigma(d) = \sigma_0\left(d+\theta\right)^{-\eta-\eta_2}$$
$$\xi = \xi_0$$

Add flexibility to d-GEV



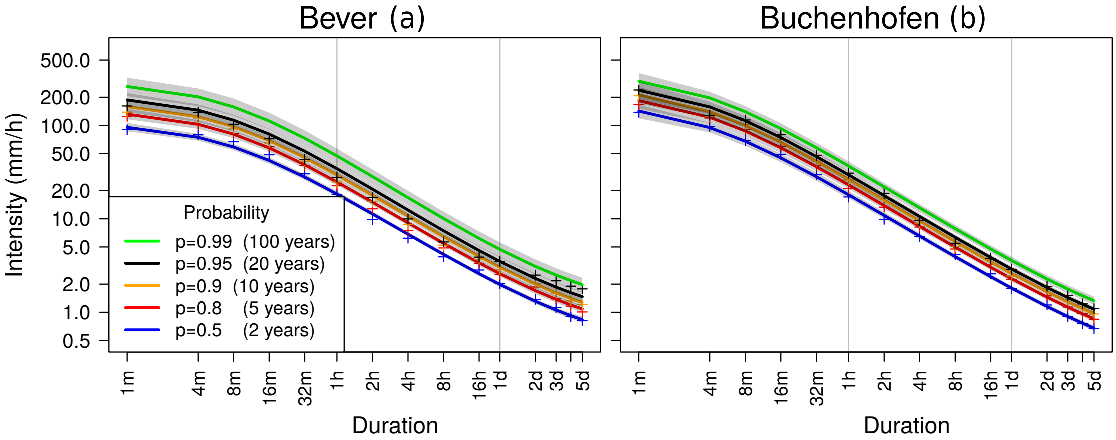
$$G(z) = \exp\left\{-\left[1+\xi\left(\frac{z-\mu(d)}{\sigma(d)}\right)\right]^{-1/\xi}\right\}$$

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

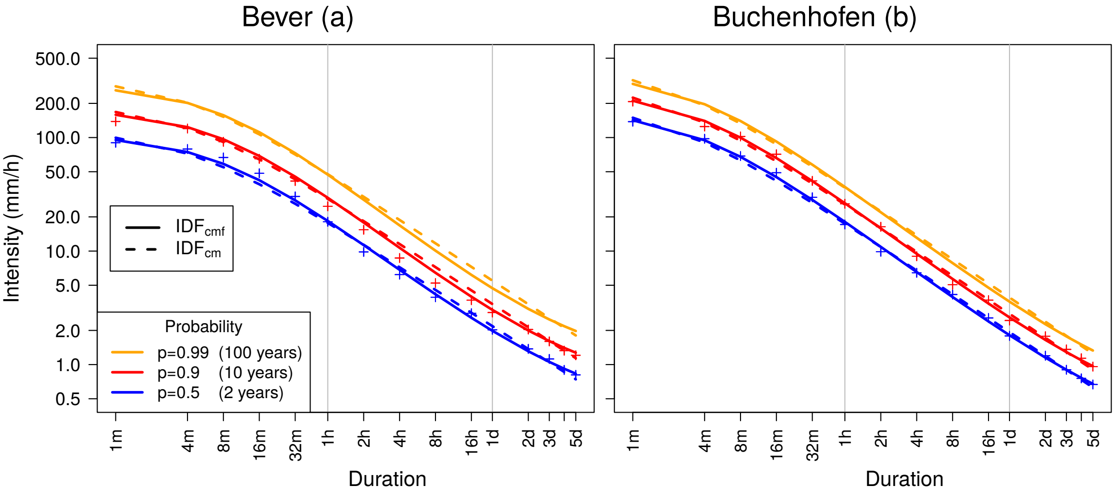
$$\sigma(d) = \sigma_0\left(d+\theta\right)^{-\eta-\eta_2}+\tau$$

$$\xi = \xi_0$$

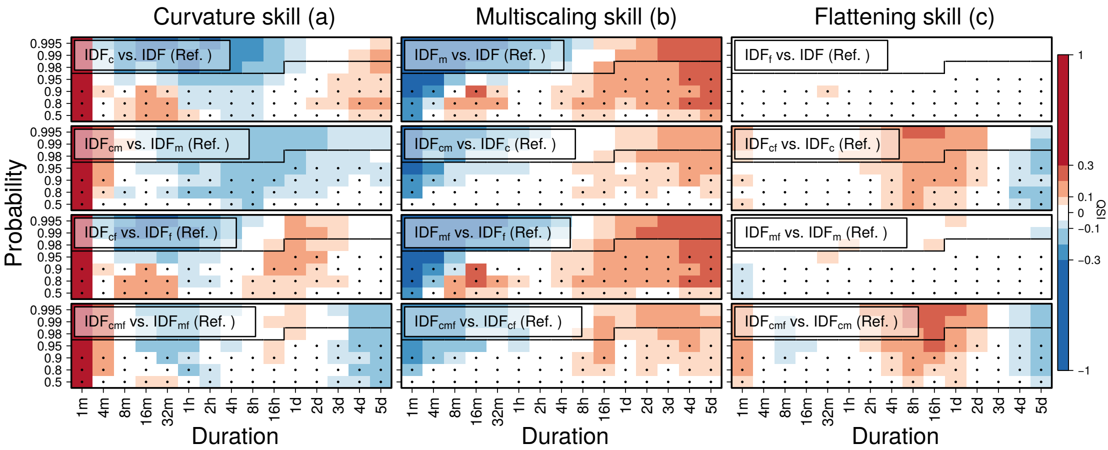
Flexible IDF example: Bever and Buchenhofen



Flexible IDF example: Bever and Buchenhofen

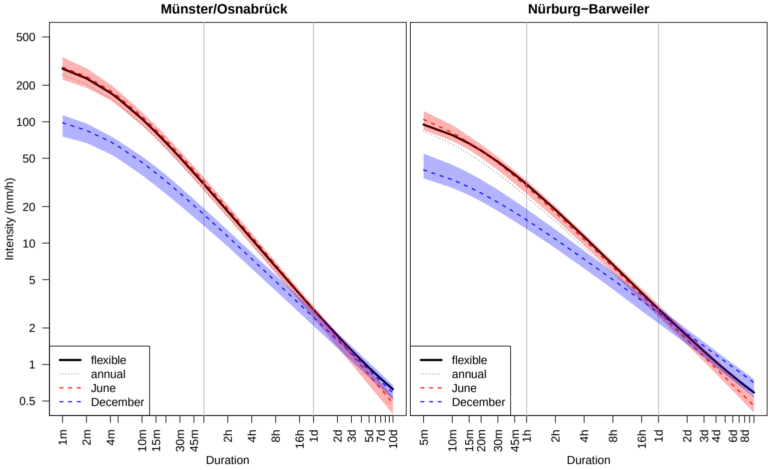


Improvement due to individual features



Average over 92 station in the Wupper catchment.

Flexible d-GEV accounts for various Processes



Summary and Reference

Summary

- added flexibility can be useful
- „flattening“ needed when mixing processes with different slopes η (seasons)

Reference

Flexible and consistent quantile estimation for intensity–duration–frequency curves
F. Fauer, J. Ulrich, H. Rust
Hydrology and Earth System Sciences, 25.12 (2021): 6479-6494
`https://hess.copernicus.org/articles/25/6479/2021/`

Summary and Outlook

Summary

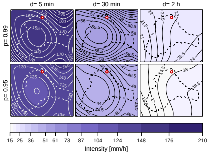
- d-GEV to exploit smoothness across durations
- detailled verification with QVS
- seasonal IDF curves
- added flexibility (account for mixture of processes)

Outlook

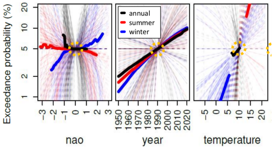
- projecting IDF relations based on global climate models
- extended GEV to compensate for deviations from GEV
- combine grid-based and gauge data
- use smooth (GAM-like) relations instead of parametric

IDF

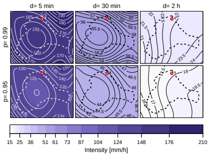
https://cran.r-project.org/web/packages/IDF/index.html



Spatial covariates

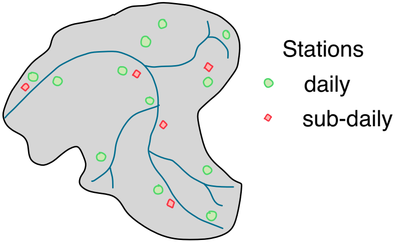


IDF with covariates

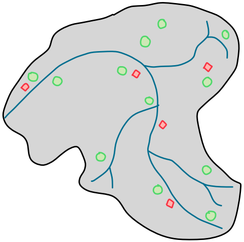


Spatial covariates

Motivation



Motivation



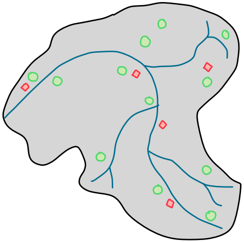
Stations

daily

sub-daily

more stations
+
longer time series

Motivation



Stations

daily

sub-daily

→ more stations + longer time series

Aim:

transfer knowledge

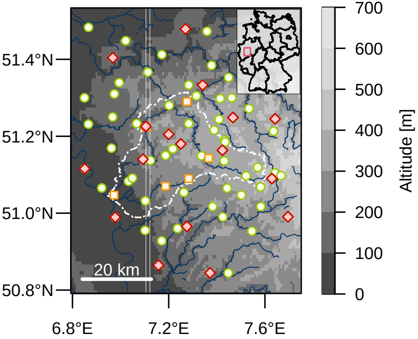
pool information

space

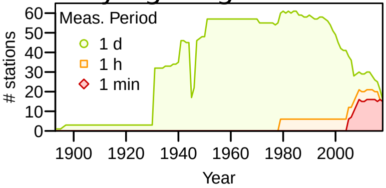
throughout the year

Precipitation Data

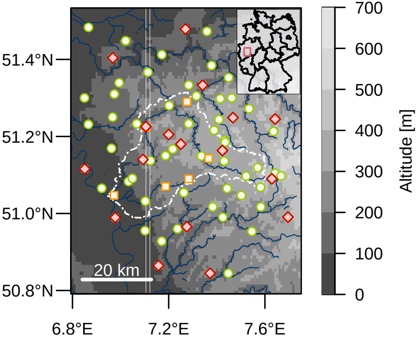
- Case study **Wupper-Catchment**:
  - 92 gauges in 75 locations
  - provided by DWD and Wupperverband



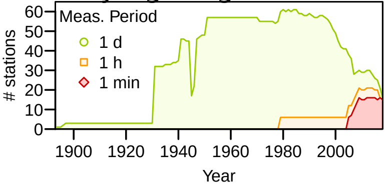
- different measuring periods
- varying length of time series



- Case study **Wupper-Catchment**:
  - 92 gauges in 75 locations
  - provided by DWD and Wupperverband



- different measuring periods
- varying length of time series



Aim:

- model all stations simultaneously
- IDF curves for every location

Research Questions:

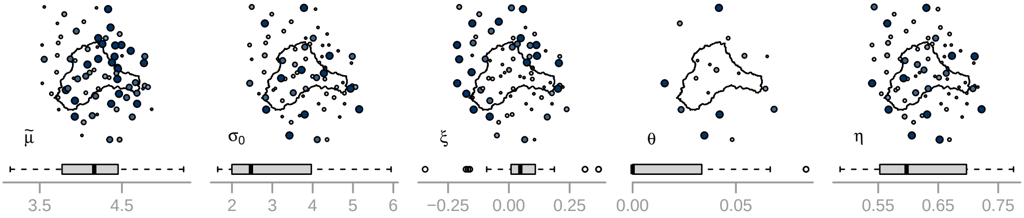
- Can we improve IDF estimation?
- Also at ungauged sites?

Spatial Covariates

- Model annual maxima for durations using the d-GEV

  1 ,4, 8, 16, 32 minutes,
  1, 2, 3, 8, 16 hours and
  1, 2, 3, 4, 5 days

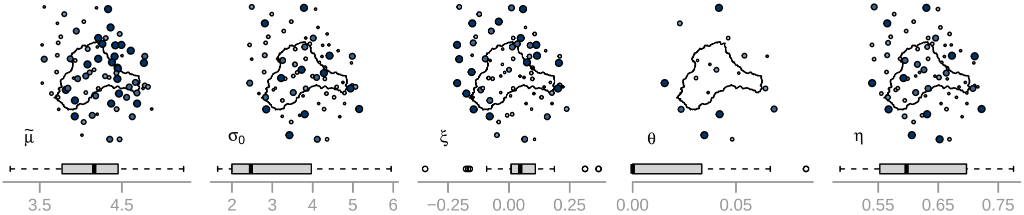
$$G(z, d; \tilde{\mu} \quad, \sigma_0 \quad, \xi \quad, \theta \quad, \eta \quad)$$



- Model annual maxima for durations
  1 ,4, 8, 16, 32 minutes,
  1, 2, 3, 8, 16 hours and
  1, 2, 3, 4, 5 days

at all locations using the d-GEV with spatial covariates

$$G(z, d;\ \tilde{\mu}(\vec{r}),\ \sigma_0(\vec{r}),\ \xi(\vec{r}),\ \theta(\vec{r}),\ \eta(\vec{r})\ )$$



Spatial Covariates

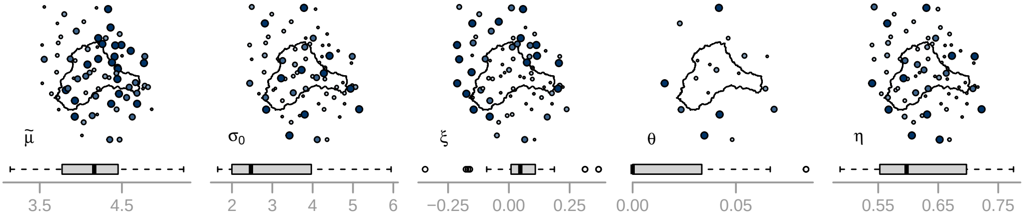
- Model annual maxima for durations
  1 ,4, 8, 16, 32 minutes,
  1, 2, 3, 8, 16 hours and
  1, 2, 3, 4, 5 days

  at all locations using the d-GEV with spatial covariates

  $$G(z, d;\ \tilde{\mu}(\vec{r}),\ \sigma_0(\vec{r}),\ \xi(\vec{r}),\ \theta(\vec{r}),\ \eta(\vec{r})\ )$$

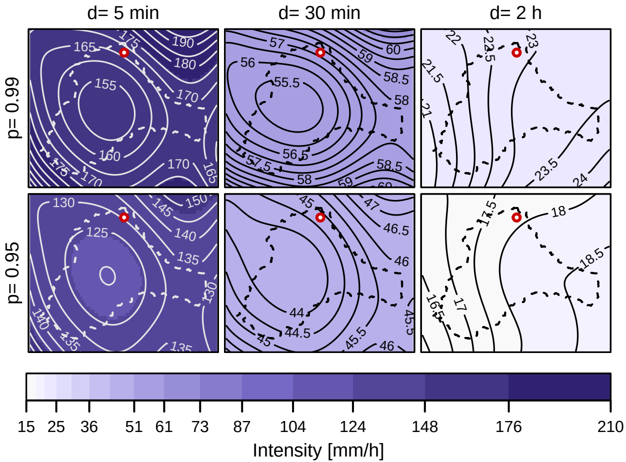
- Orthogonal polynomials of lon and lat[1] for all $\phi \in \{\tilde{\mu}, \sigma_0, \xi, \theta, \eta\}$

$$\phi(\vec{r}) = \phi_0 + \sum_{j=1}^{J} \beta_j^{\phi} P_j(\text{lon}) + \sum_{k=1}^{K} \gamma_k^{\phi} P_k(\text{lat}) + \sum_{j=1}^{J} \sum_{k=1}^{K} \delta_{j,k}^{\phi} P_j(\text{lon}) P_k(\text{lat})$$



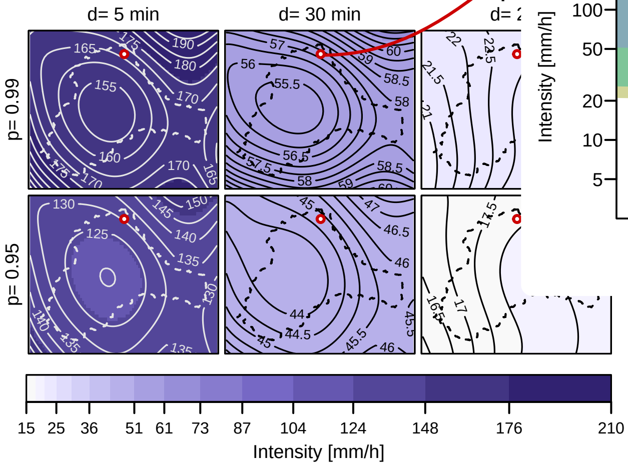
[1] e.g. Fischer et al. *Spat. Stat.* 2019, 34:100275

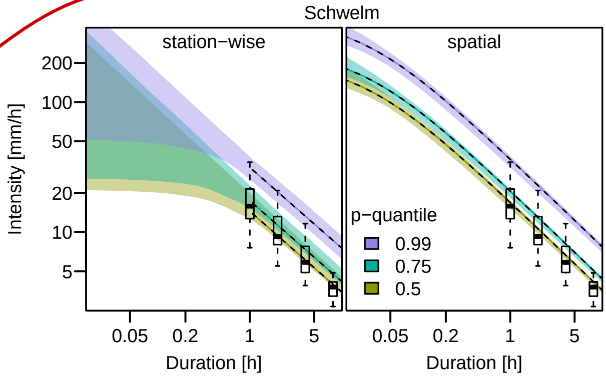
Return levels for various durations and non-exceedance probabilities



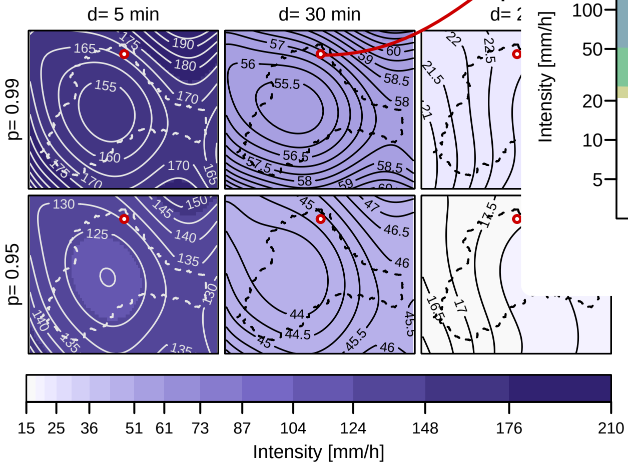
Results

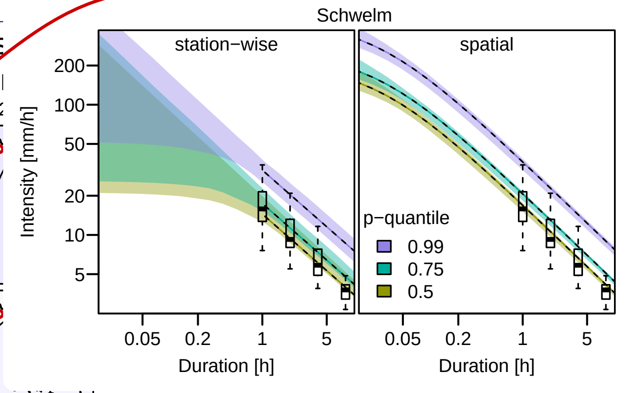
Return levels for various ... ons and non-exceedance p...





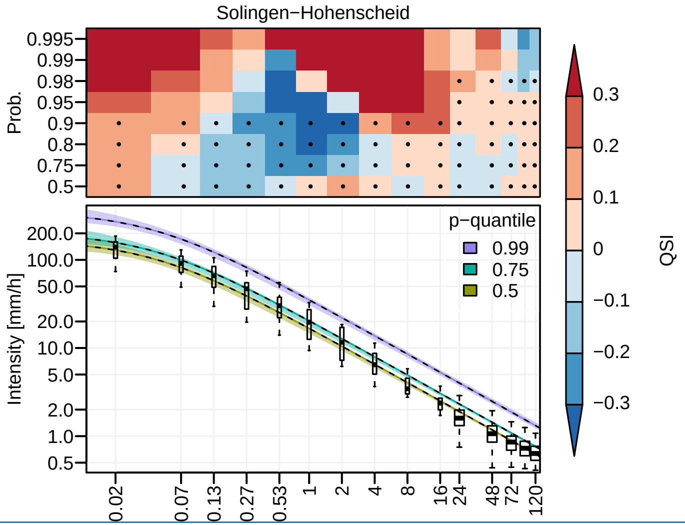
Return levels for various ... ons and non-exceedance p...



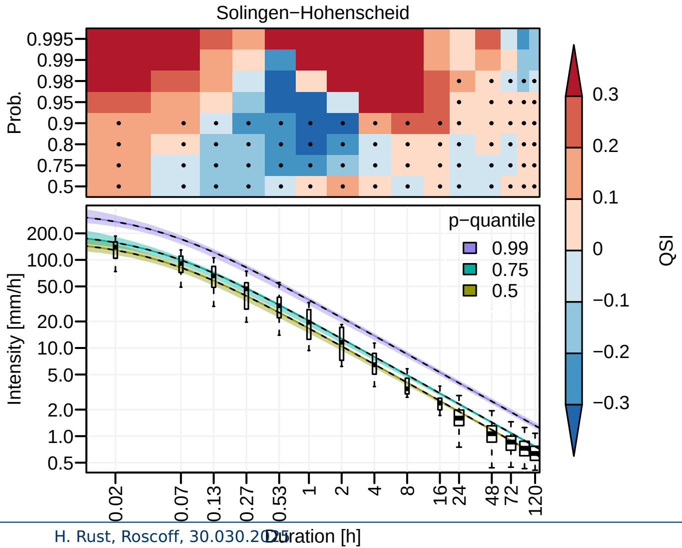


- reduced uncert.
- estimates ungauged durations/ locations

Results

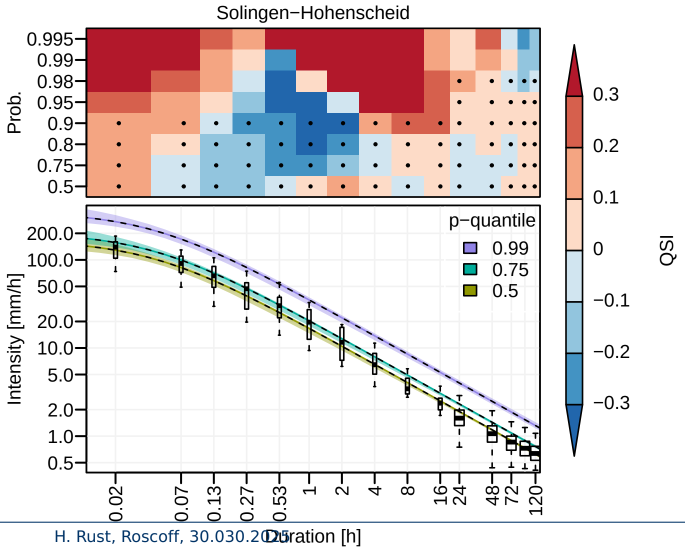


Solingen−Hohenscheid
Prob.
0.995
0.99
0.98
0.95
0.9
0.8
0.75
0.5
p−quantile
0.99
0.75
0.5
Intensity [mm/h]
200.0
100.0
50.0
20.0
10.0
5.0
2.0
1.0
0.5
0.02
0.07
0.13
0.27
0.53
1
2
4
8
16
24
48
72
120
Duration [h]
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
QSI



Methods

- Quantile Score: compare modeled quantiles to observations
- Quantile Skill Index: compare performance of spatial d-GEV model with reference (separate GEV)



Methods

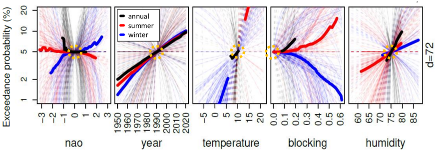
- Quantile Score: compare modeled quantiles to observations
- Quantile Skill Index: compare performance of spatial d-GEV model with reference (separate GEV)

Results

- improvement for rare events
- Improvement for short series
- $d \geq 24\,\mathrm{h} \rightarrow$ more data, pooling less important
- not all durations show improvement → lack of flexibility

Reference

Estimating IDF curves consistently over durations with spatial covariates.
Jana Ulrich, Oscar Jurado, Madlen Peter, Marc Scheibel and Henning Rust
Water, 12(11), 3119
`https://www.mdpi.com/2073-4441/12/11/3119`



IDF with covariates

IDF paramters depending on large scale variables

→ Distribution parameters: function of large-scale variable

Include large-scale information

- polynomial up to 4th order
- each d-GEV parameter can depend on up to two large-scale variables
- Stepwise BIC model selection
- Cross-validated (2-fold)
- No spatial dependence

$f(x)$: Polynomial regression

Examples for dependencies of d-GEV parameters

(scale offset)	$\sigma_0(x)$	$= f(x_1)$
(rescaled location)	$\tilde{\mu}(x)$	$= f(x_2)$
(shape)	$\xi(x)$	$= f(x_1^2)$
(curvature)	$\theta(x)$	$= (constant)$
(duration exponent)	$\eta(x)$	$= f(x_1^2) + f(x_2^3)$
(multiscaling)	$\eta_2(x)$	$= f(x_3)$
(intensity offset, flattening)	$\tau(x)$	$= f(x_1) + f(x_3)$

Example large-scale variables

x_1 - NAO
x_2 - temperature
...

Large scale variables

<u>Temperature and humidity</u>

- ERA5, 0.25°
- 4°W-15°W, 45°N-55°N (average)

<u>Binary Blocking-Index (BBI)</u>

- Scherrer et al, 2006
- ERA5, area mean over SCA

→ all 1950-2015

<u>North-Atlantic Oscill. (NAO) index</u>

- NOAA, PCA-based

→ all averaged over month/year

(Fauer, Rust, 2023)

Temperature and humidity
- ERA5, 0.25°
- 4°W-15°W, 45°N-55°N (average)

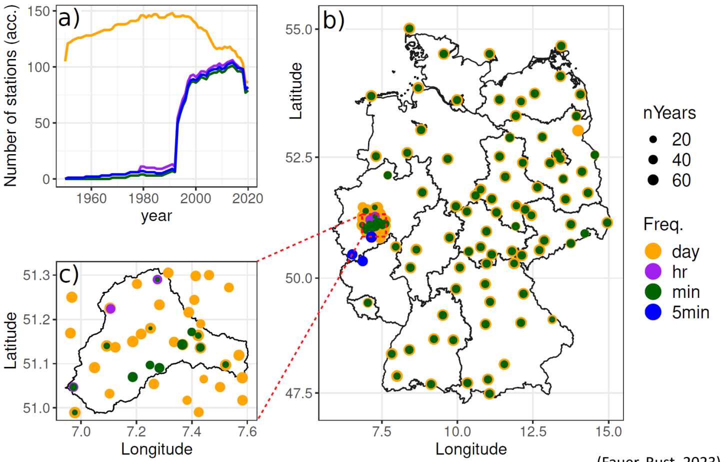
Binary Blocking-Index (BBI)
- Scherrer et al, 2006
- ERA5, area mean over SCA

→ all 1950-2015

North-Atlantic Oscill. (NAO) index
- NOAA, PCA-based

→ all averaged over month/year

Precipitation
- DWD, Wupperverband
- station-based data
- different temporal resolutions



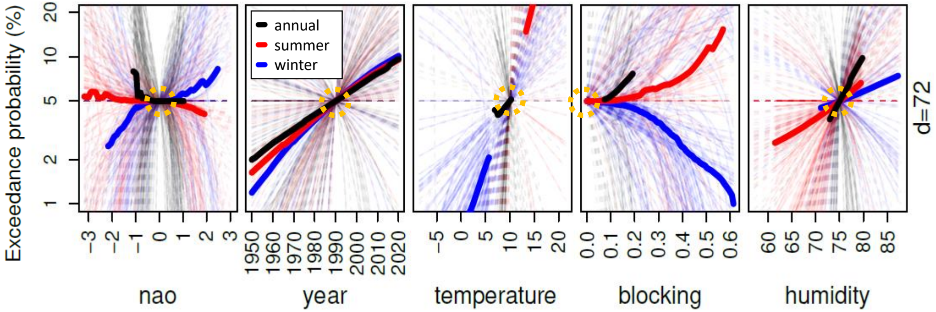
(Fauer, Rust, 2023)

Results for observed covariate dependence

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

Reference event at

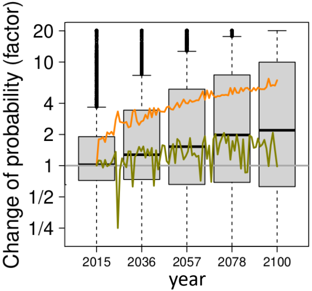
- Probability $p = 5\%$
- NAO $n = 0$
- Year $y = 1990$
- Temperature $T = 10°C$
- Blocking $b = 0$
- Humidity $h = 75\%$

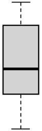


(Fauer, Rust, 2023)

Results for projections

- Simulate changes of probability ↕ in changing large-scale conditions ↔
- Projections from MPI-ESM for temperature , humidity, year





Distribution of 197 stations

Summary and Reference

summary

- IDF depends on atmospheric quantities
- study processes
- climate change projections for IDF, ’year’ as proxy for climate change

Reference

Non-stationary large-scale statistics of precipitation extremes in central Europe
F. Fauer and H. Rust
Stoch Environ Res Risk Assess 37, 4417–4429 (2023)
`https://doi.org/10.1007/s00477-023-02515-z`