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Predicting extreme sub-hourly precipitation intensification based on temperature shifts

Proiezioni di precipitazioni estreme sub-orarie sulla base delle temperature future

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sub-hourly extreme precipitation

what do we mean by extreme?

- We need projections of future, very rare extreme precipitation, at sub-hourly scales
- We are interested in low exceedance probability in time
  (annual exceedance probability)
- Example: the 100-year event (or *return level*)
  - 1% probability of being exceeded in any given year
  - expected on average once every 100 years
- These events are so rare that we have only few of them in our records (if any)

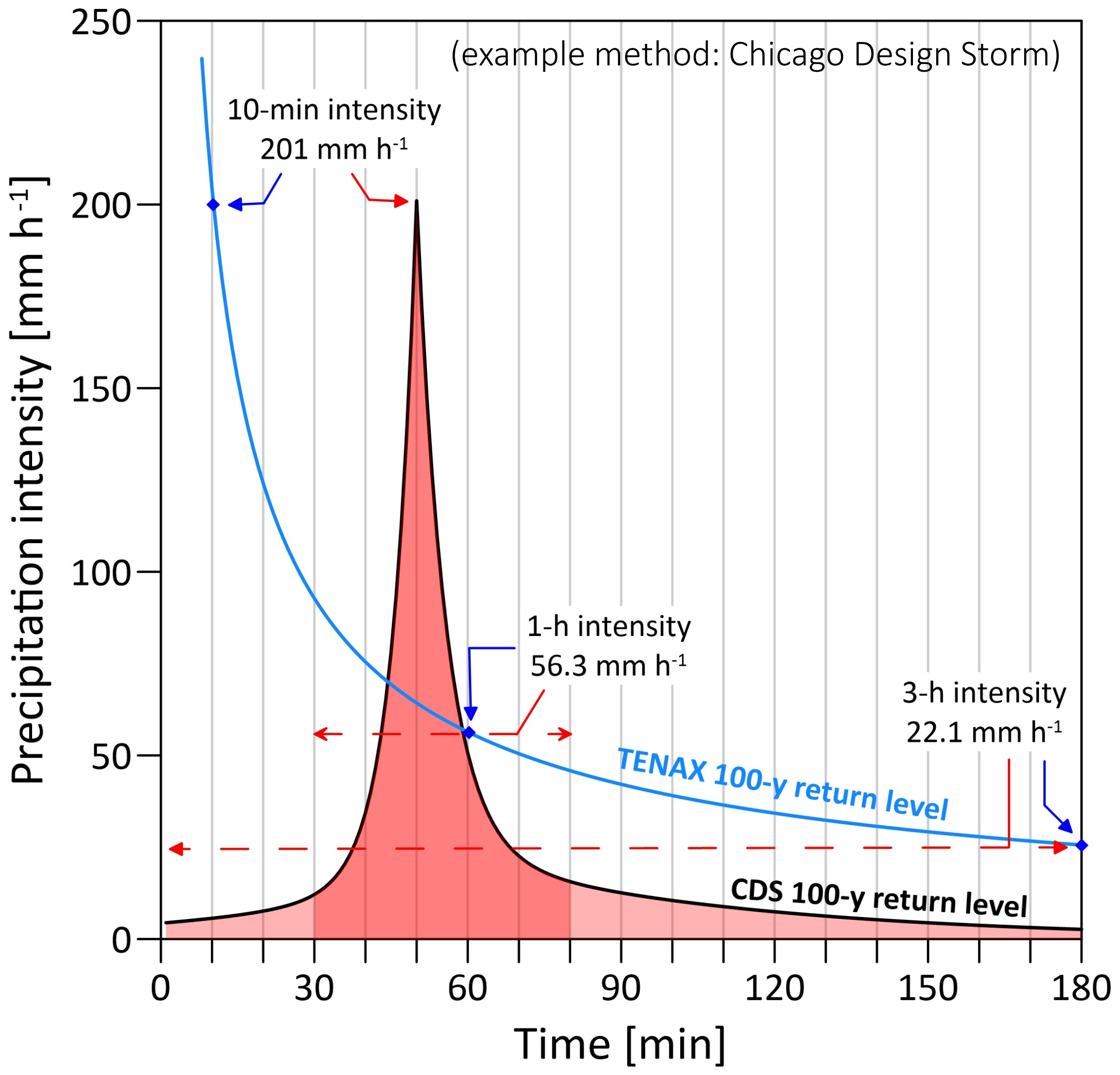
why do we need return levels?

Risk managers need probability of issuing given alerts

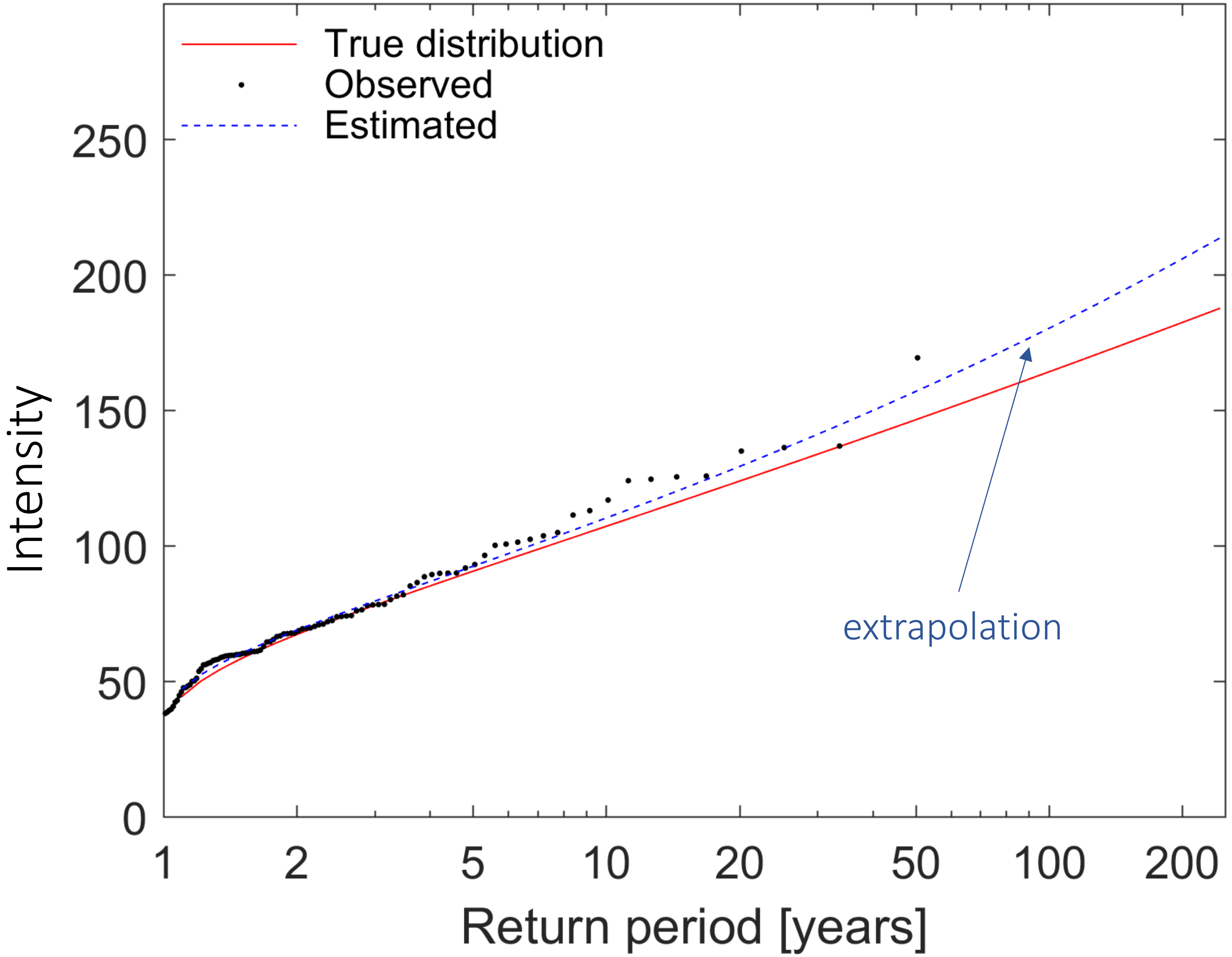
Insurers need probabilistic information about damage
(100-year events are the risk-calculation basis)

Engineers need design storms
to simulate unprecedented but possible conditions

...



first problem: statistical extrapolation

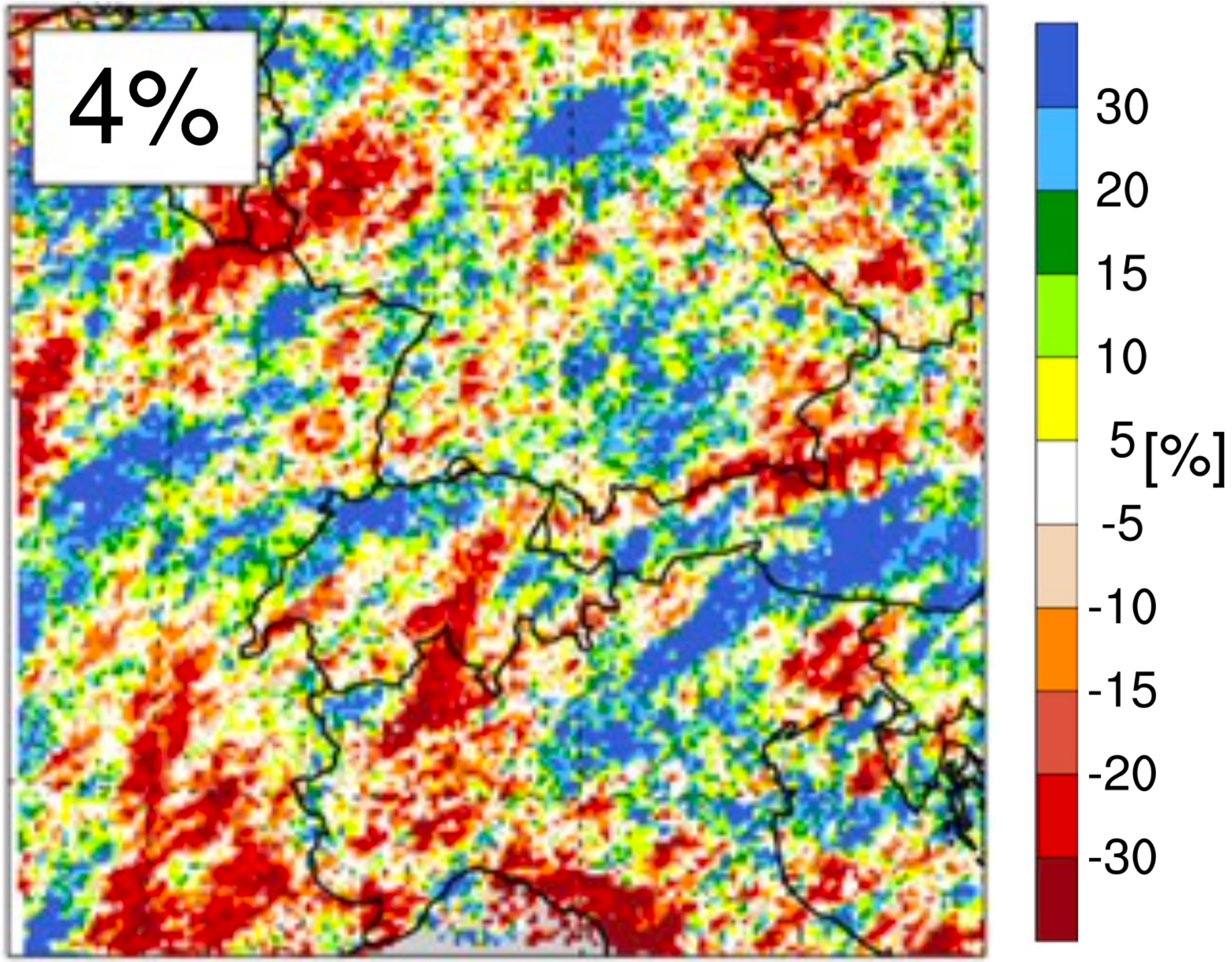


The return levels of interest are on time scales much longer than the observational records

We need some sort of statistical extrapolation

This comes with large estimation uncertainties

first problem: statistical extrapolation



% change in 10-year return levels

Traditional approach* based on
10 years of simulations

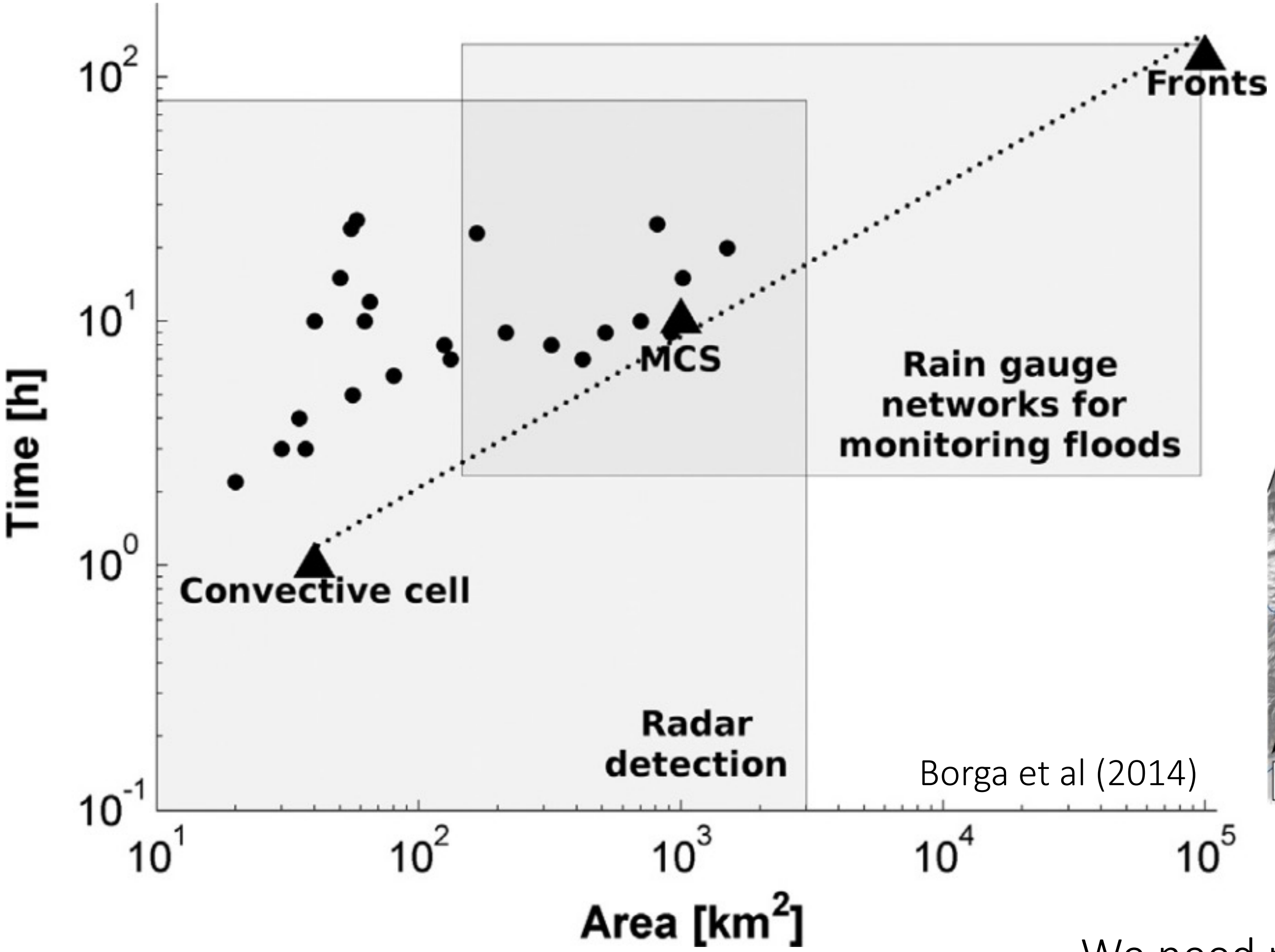
- Large uncertainty (noise)
- Contrasting projections in close by locations

- One value for the entire central Europe

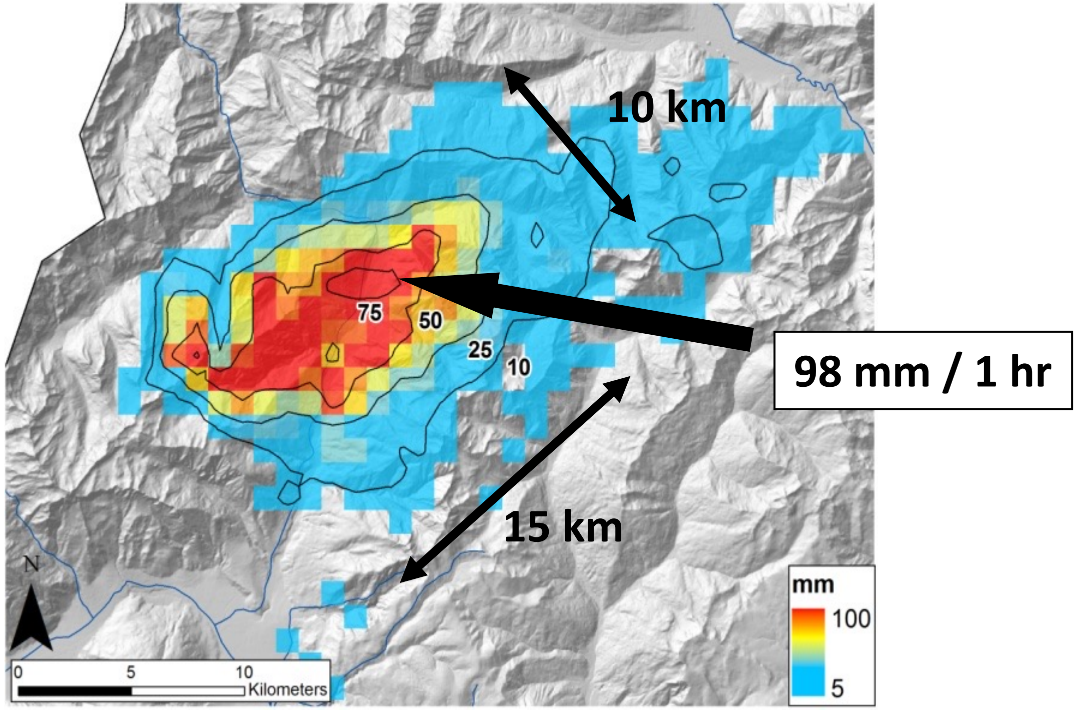
*ask me more in case

Ban & al 2020 (https://doi.org/10.1007/s00382-018-4339-4)

second problem: sub-hourly precipitation



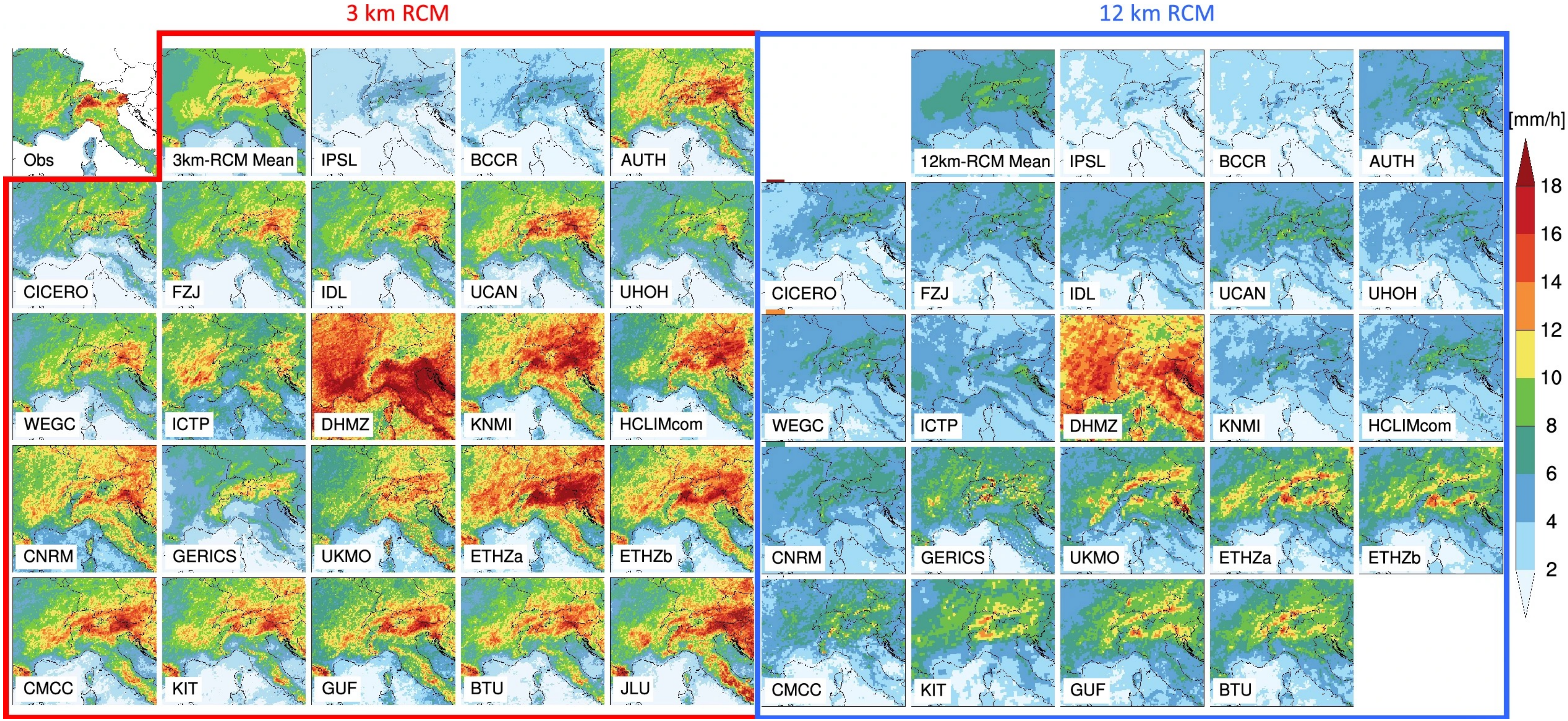
Borga et al (2014)



Marra et al (2014)

We need models able to represent convective precipitation

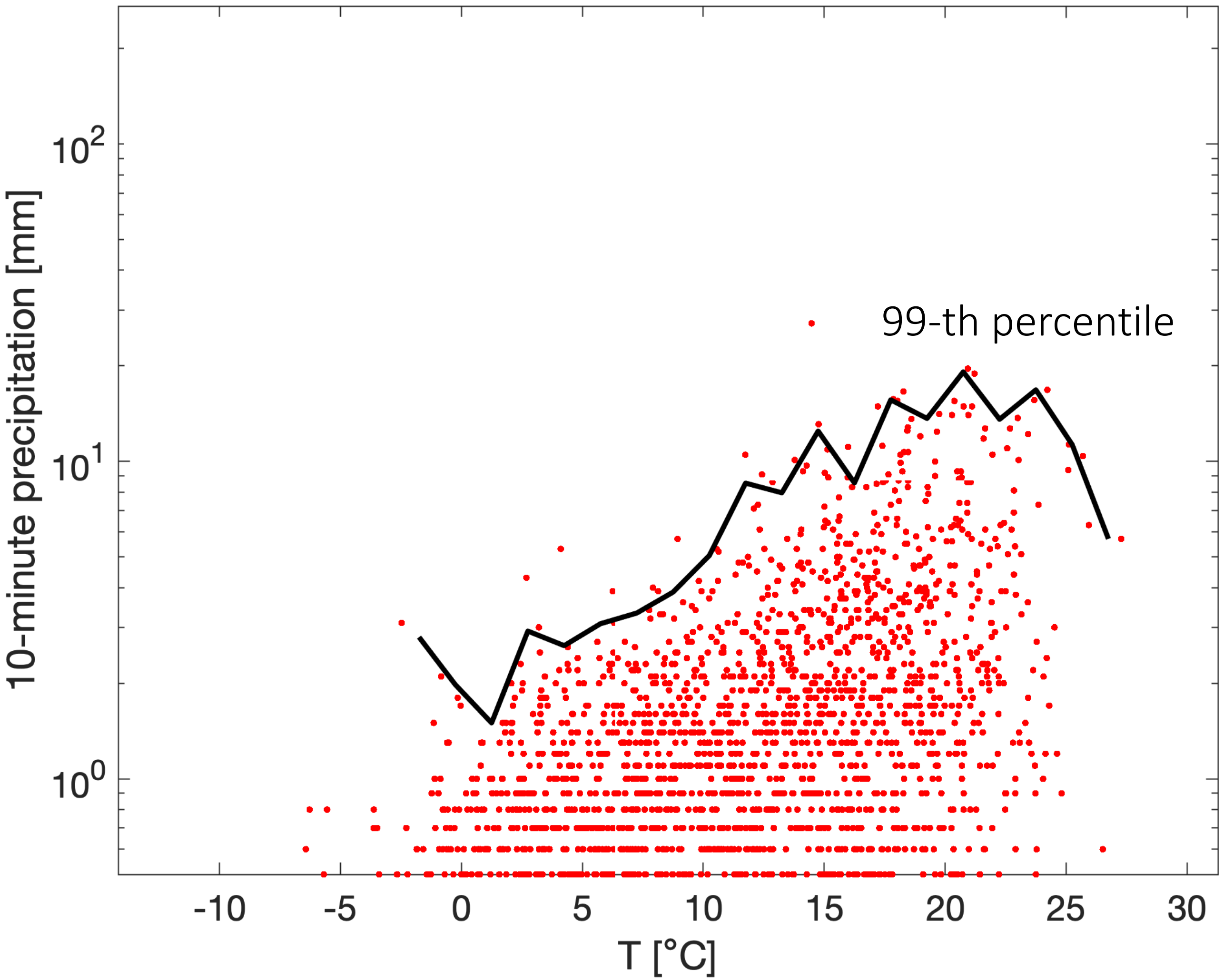
second problem: sub-hourly precipitation



Ban et al, 2020 (https://link.springer.com/article/10.1007/s00382-021-05708-w)

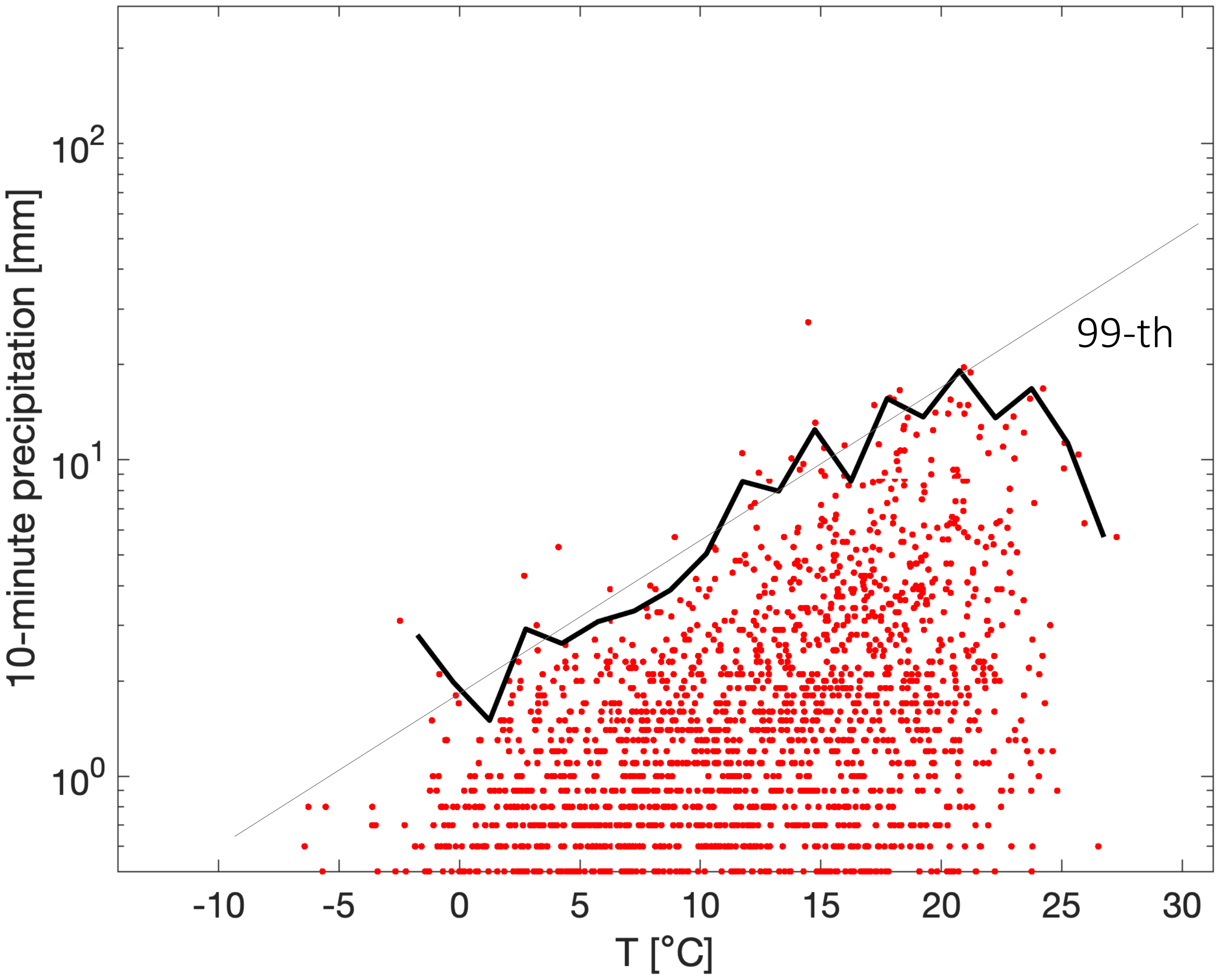
Hourly summer precipitation, 99.9th percentile

what about our physical knowledge?



Following the Clausius-Clapeyron equation, <u>extremes should increase exponentially with T</u>

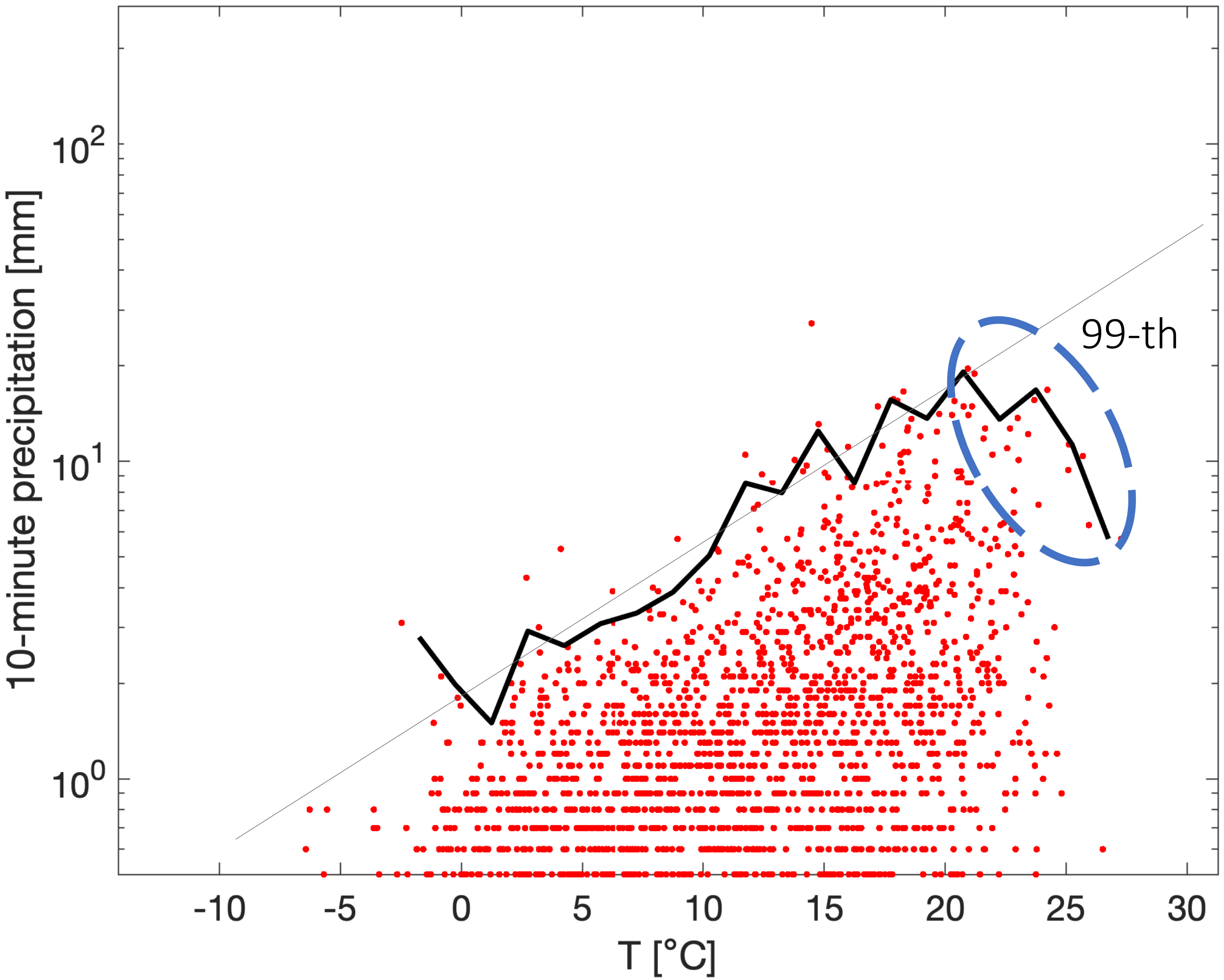
what about our physical knowledge?



Following the Clausius-Clapeyron equation, extremes should increase exponentially with T

This is approximately true for high percentiles but…

what about our physical knowledge?



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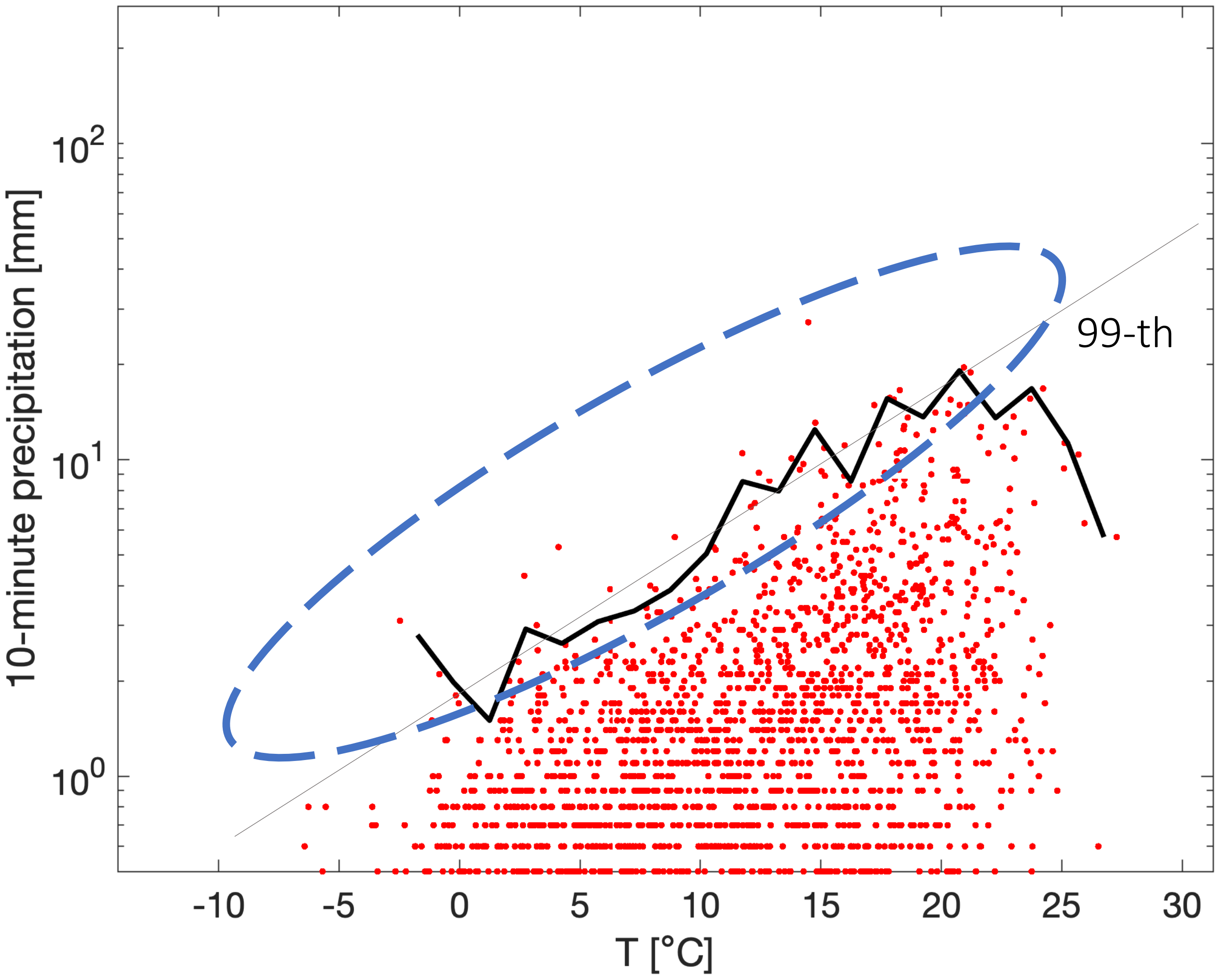
This is approximately true for high percentiles but…

1. The scaling relation often breaks at high T (what happens at higher T?)

what about our physical knowledge?



Following the Clausius-Clapeyron equation, extremes should increase exponentially with T

This is approximately true for high percentiles but...

1. The scaling relation often breaks at high T (what happens at higher T?)

2. Percentiles we can compute are too low (here we see 38 years of data, 99th percentile is exceeded several times)

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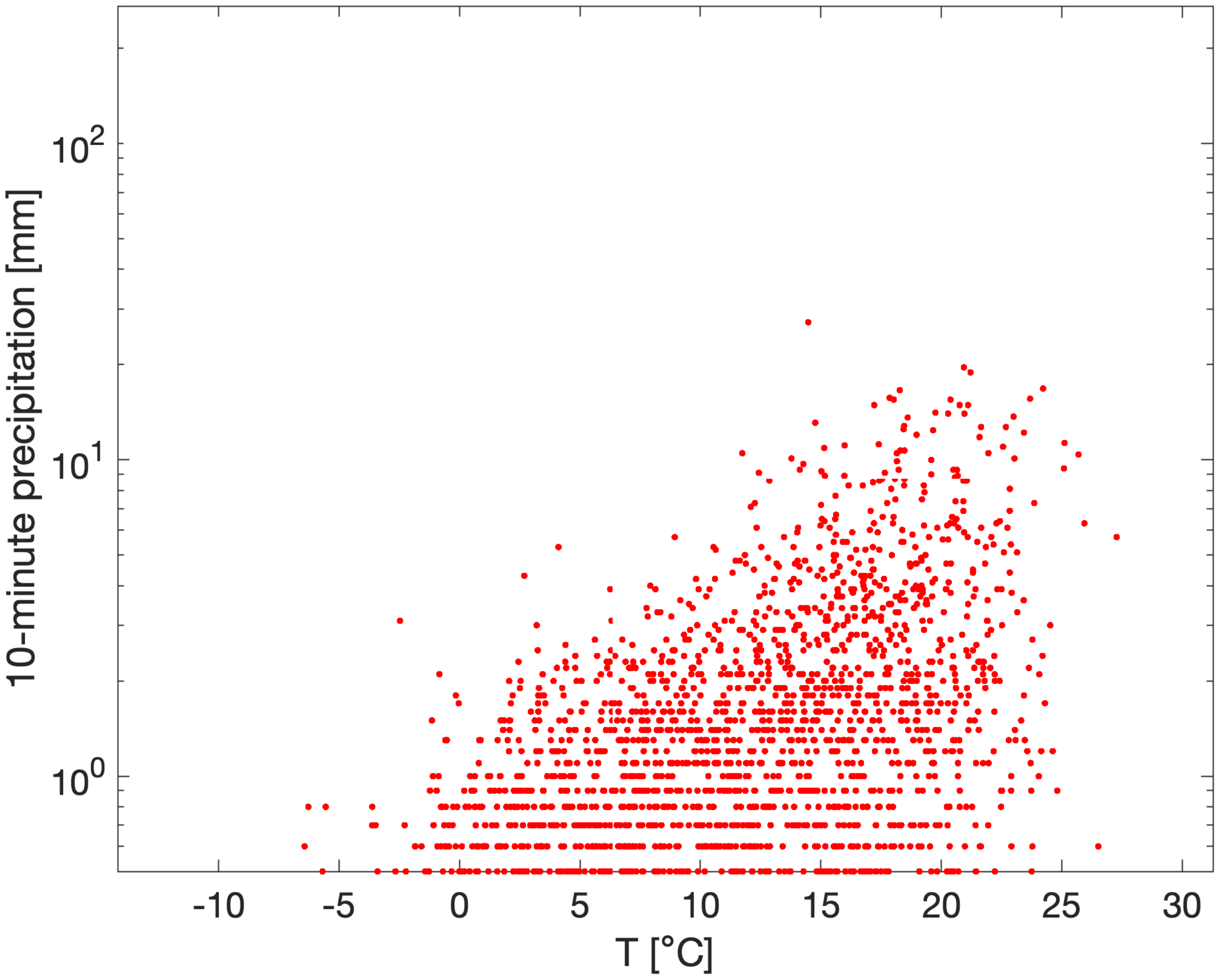
objective

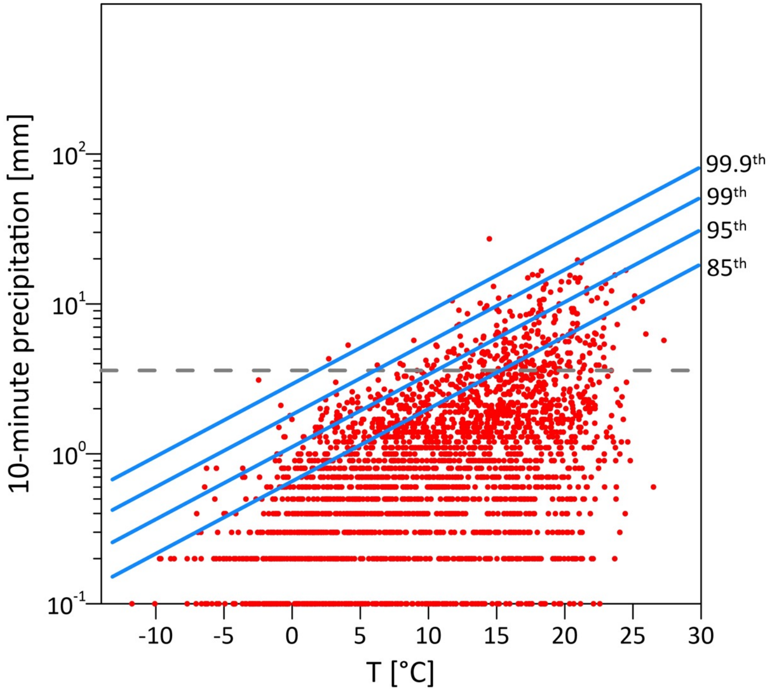


Develop an innovative statistical model to predict future sub-hourly precipitation return levels

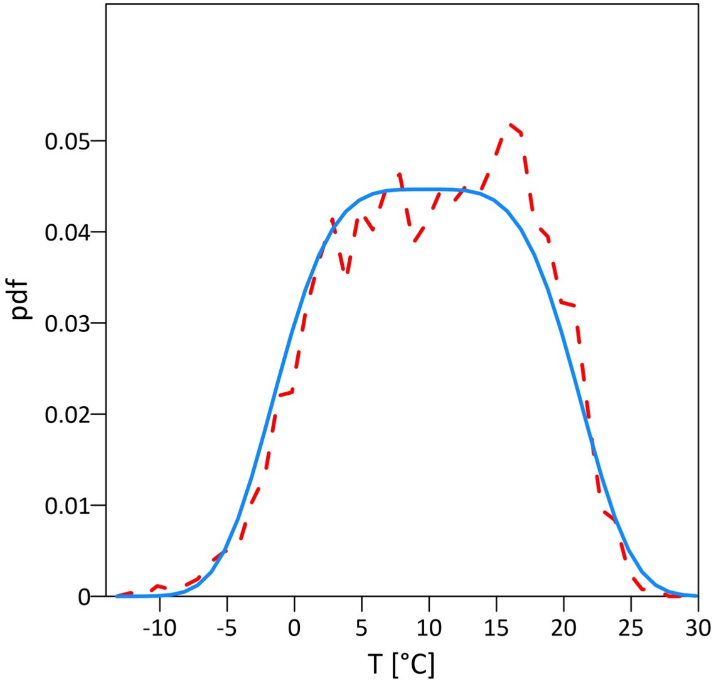
✓ Physically consistent

✓ Robust
based on variables well simulated by models

✓ Easy to use
also for practitioners and end users

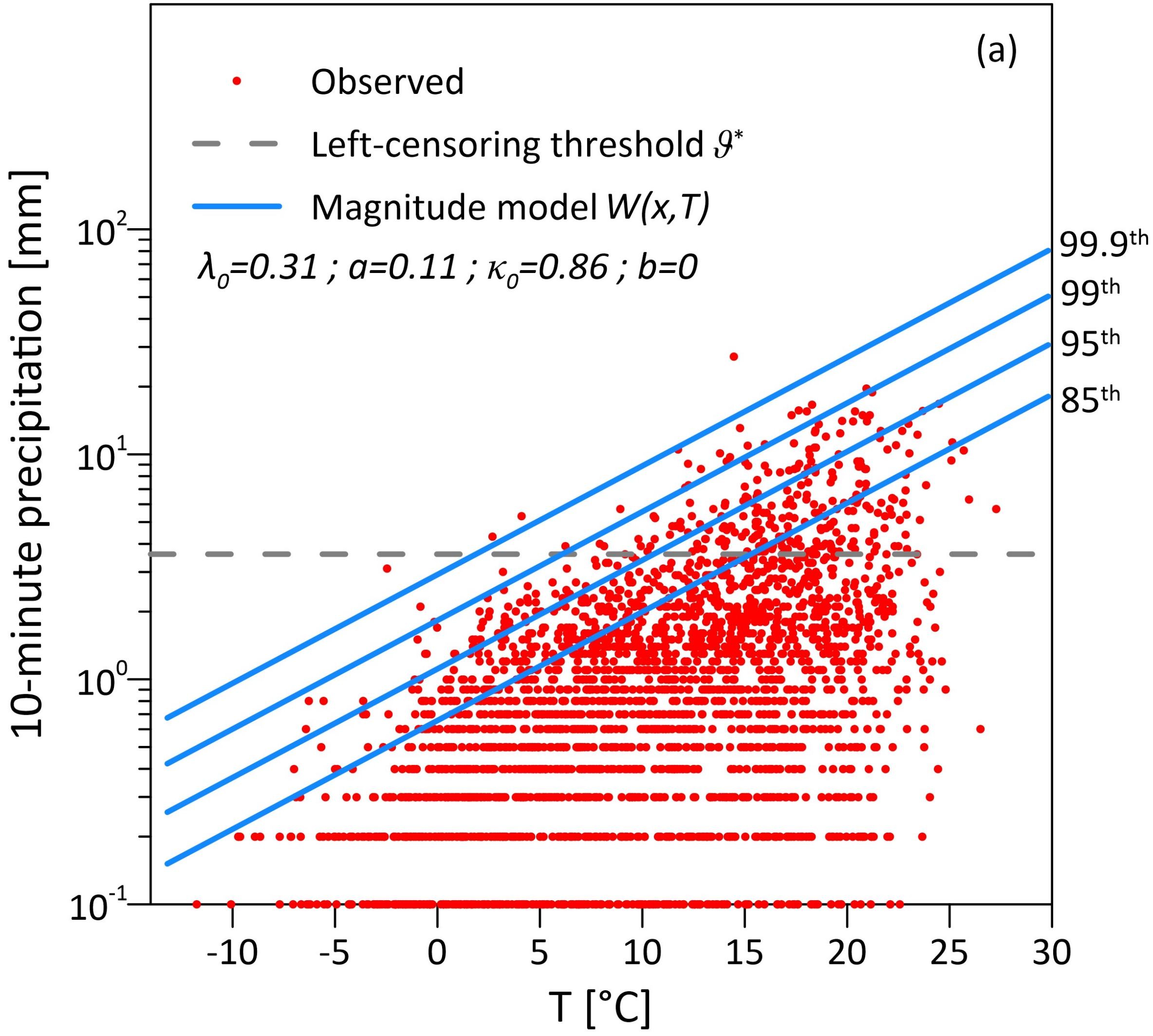


Non-stationary description of sub-hourly intensities conditioned on daily temperature



Analytical distribution of daily temperatures during wet days

magnitude model



Magnitude model

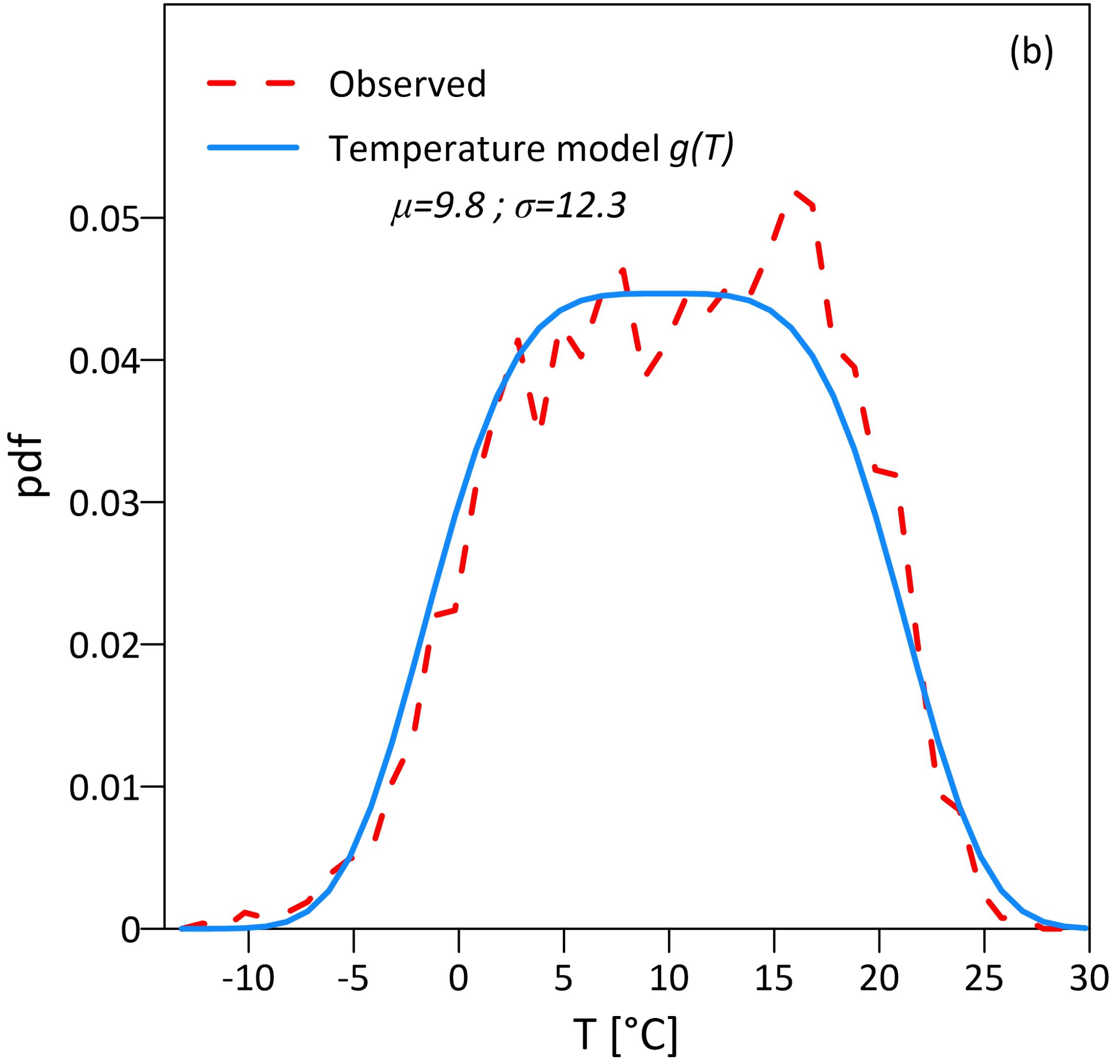
$$W(x;T) = 1 - e^{-\left[\frac{x}{\lambda(T)}\right]^{\kappa(T)}}$$

$$\lambda(T) = \lambda_0 \cdot e^{aT}$$

W: a non-stationary model to describe the exceedance probability of extreme intensities as a function of T

This model contains information about the physics of the processes at temperature T

temperature model



Magnitude model

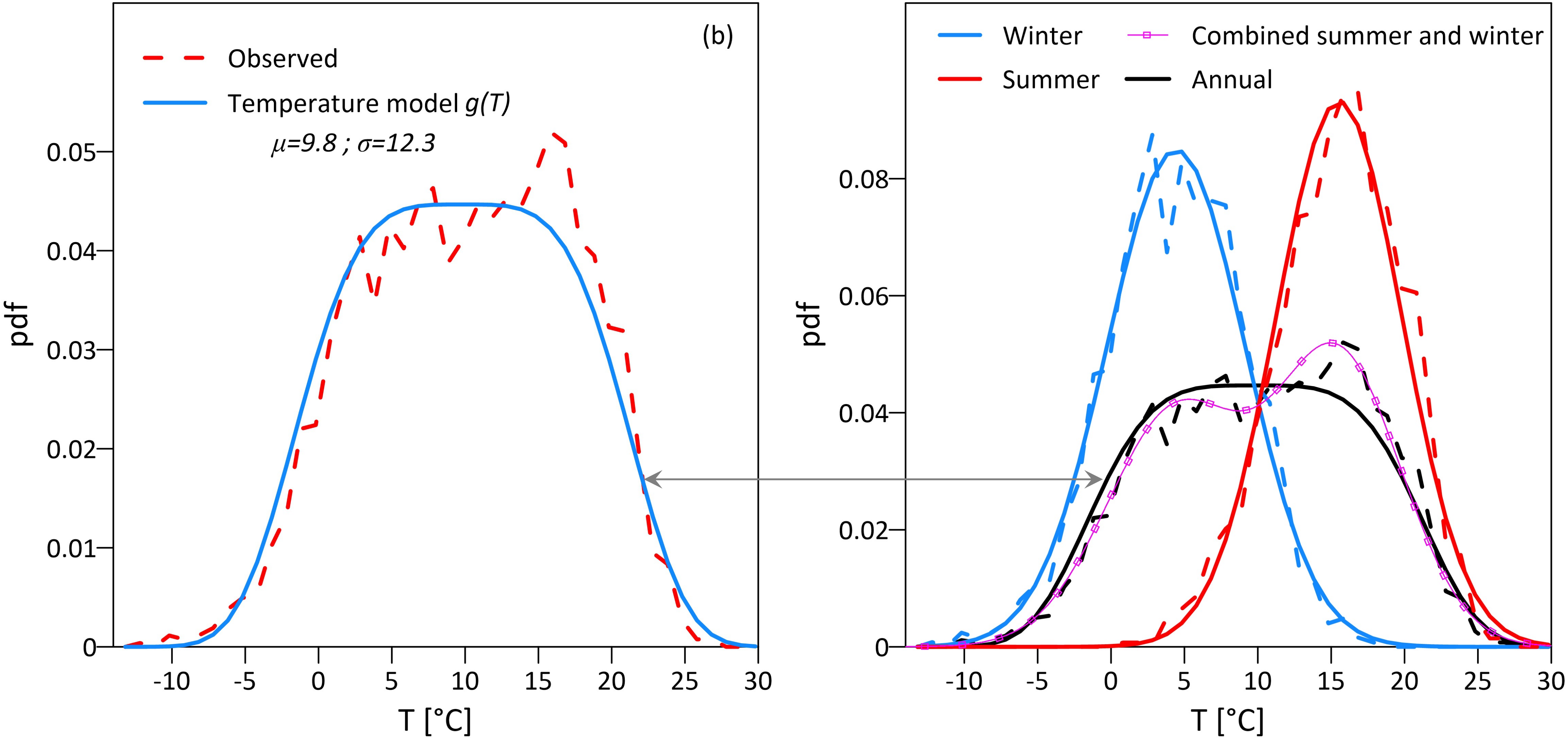
Temperature model

$$g(T) = \frac{2}{\sigma \cdot \Gamma(1/4)} \cdot \exp\left[-\left(\frac{T-\mu}{\sigma}\right)^4\right]$$

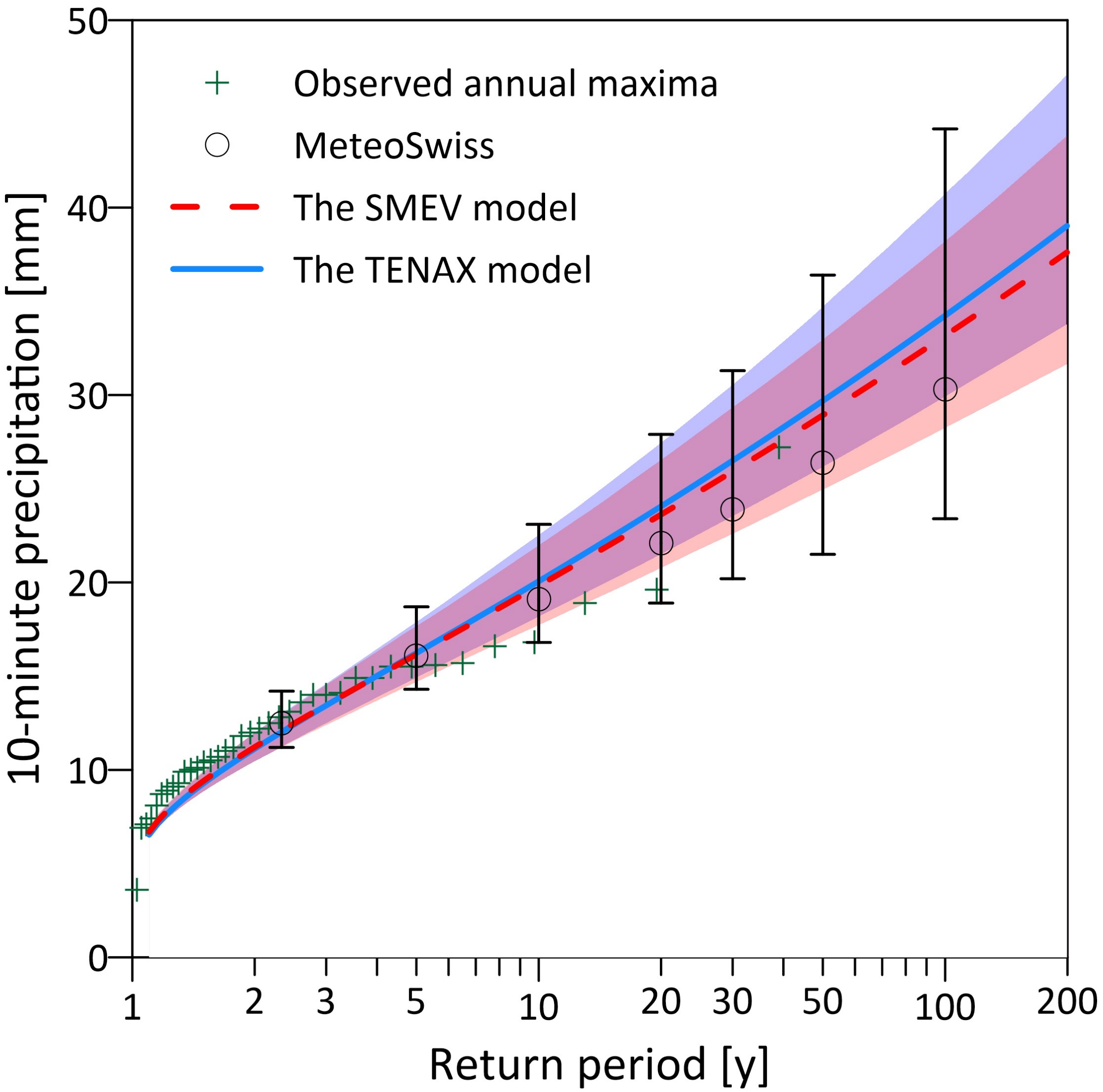
Once the magnitude model is defined, extreme return levels will depend on how temperature is sampled during events

g: describes the probability of observing a precipitation event at a given temperature (daily temperatures are used)

temperature model



TENAX: return level estimation



Magnitude model

Temperature model

Return level estimation

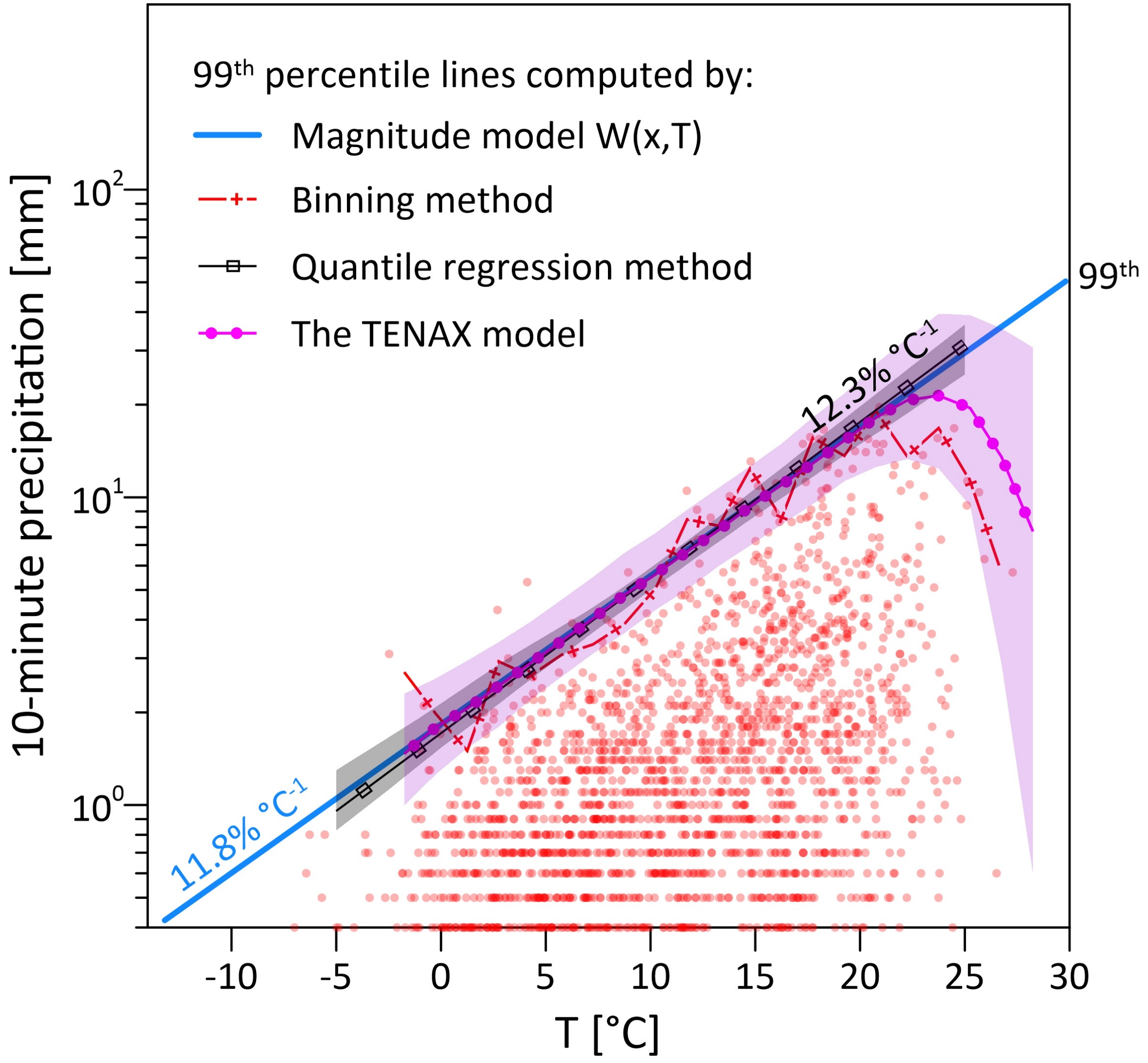
maxima from *n*-sized samples of *F(x)*: $G(x) = F(x)^n$

$$G_{\mathrm{TENAX}}(x) = \left(\int_{-\infty}^{+\infty} W(x;T) \cdot g(T)\, dT \right)^n \simeq \left(\frac{1}{N} \sum_{i=1}^{N} W(x;T_i) \right)^n$$

total probability theorem

Monte Carlo approximation

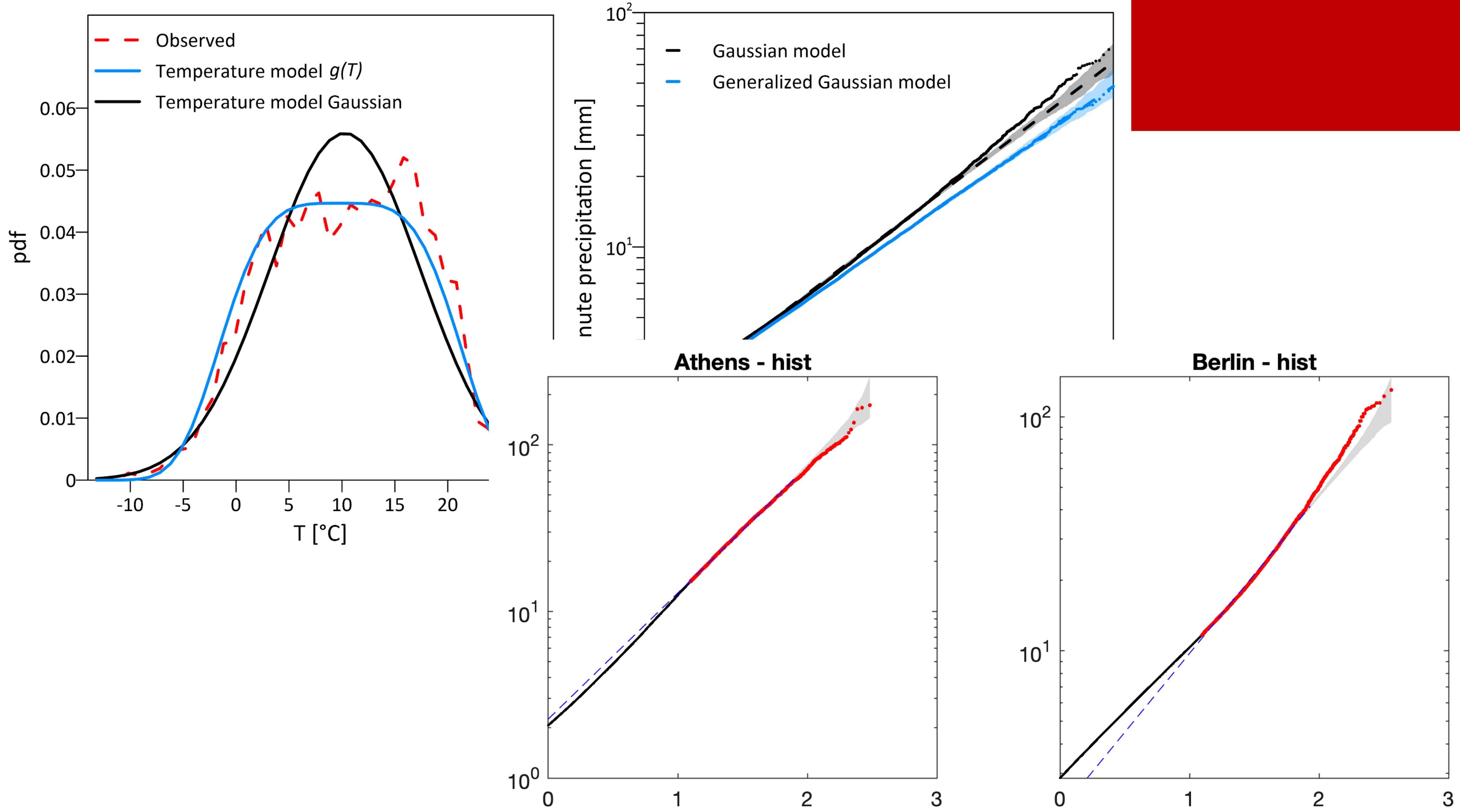
TENAX explains our observations



Magnitude model

Temperature model

Explains observed properties of extreme precipitation



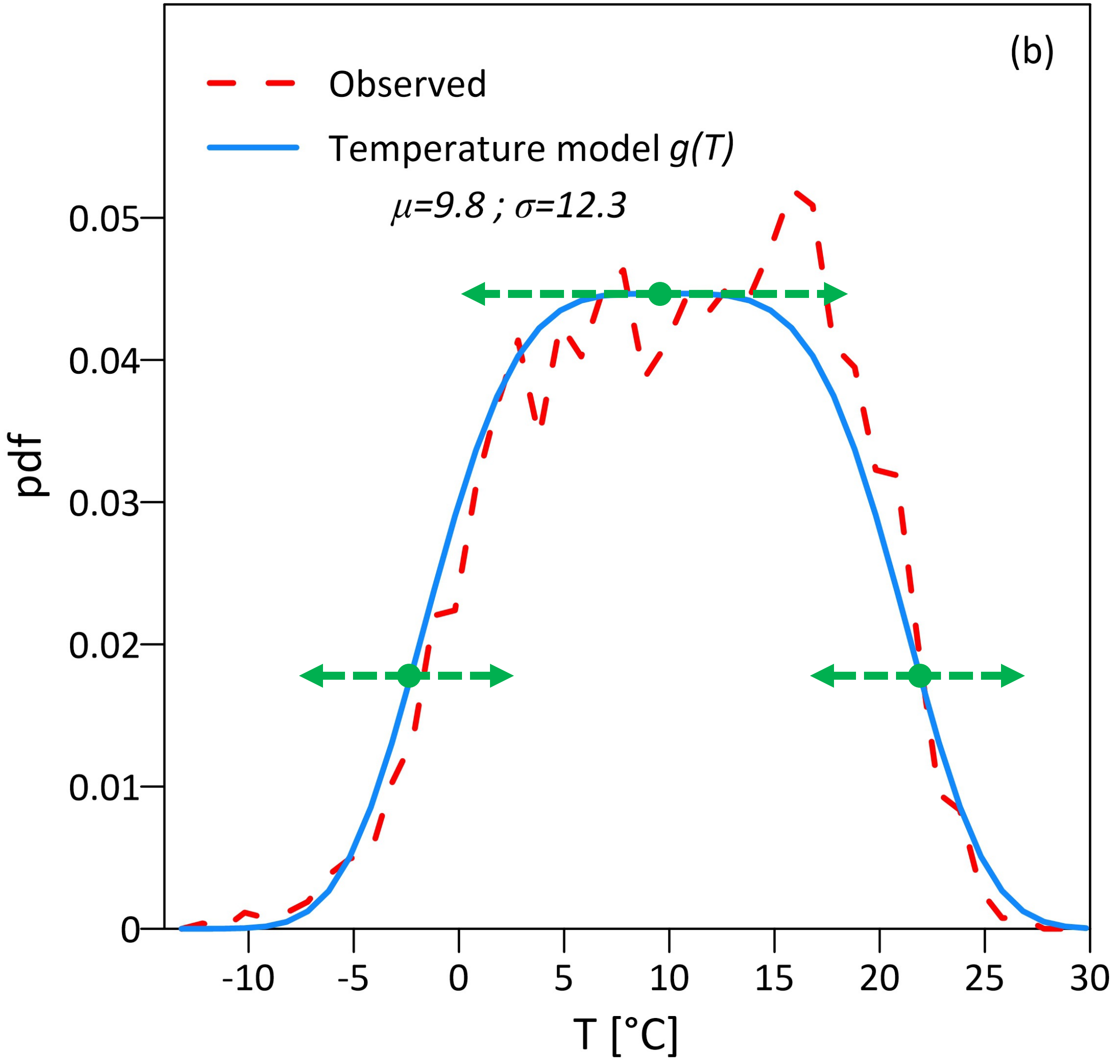
Observed
Temperature model g(T)
Temperature model Gaussian
pdf
0.06
0.05
0.04
0.03
0.02
0.01
0
-10
-5
0
5
10
15
20
T [°C]
Gaussian model
Generalized Gaussian model
nute precipitation [mm]
10^2
10^1
Athens - hist
Berlin - hist
10^2
10^1
10^0
0
1
2
3

predicting future extremes with TENAX

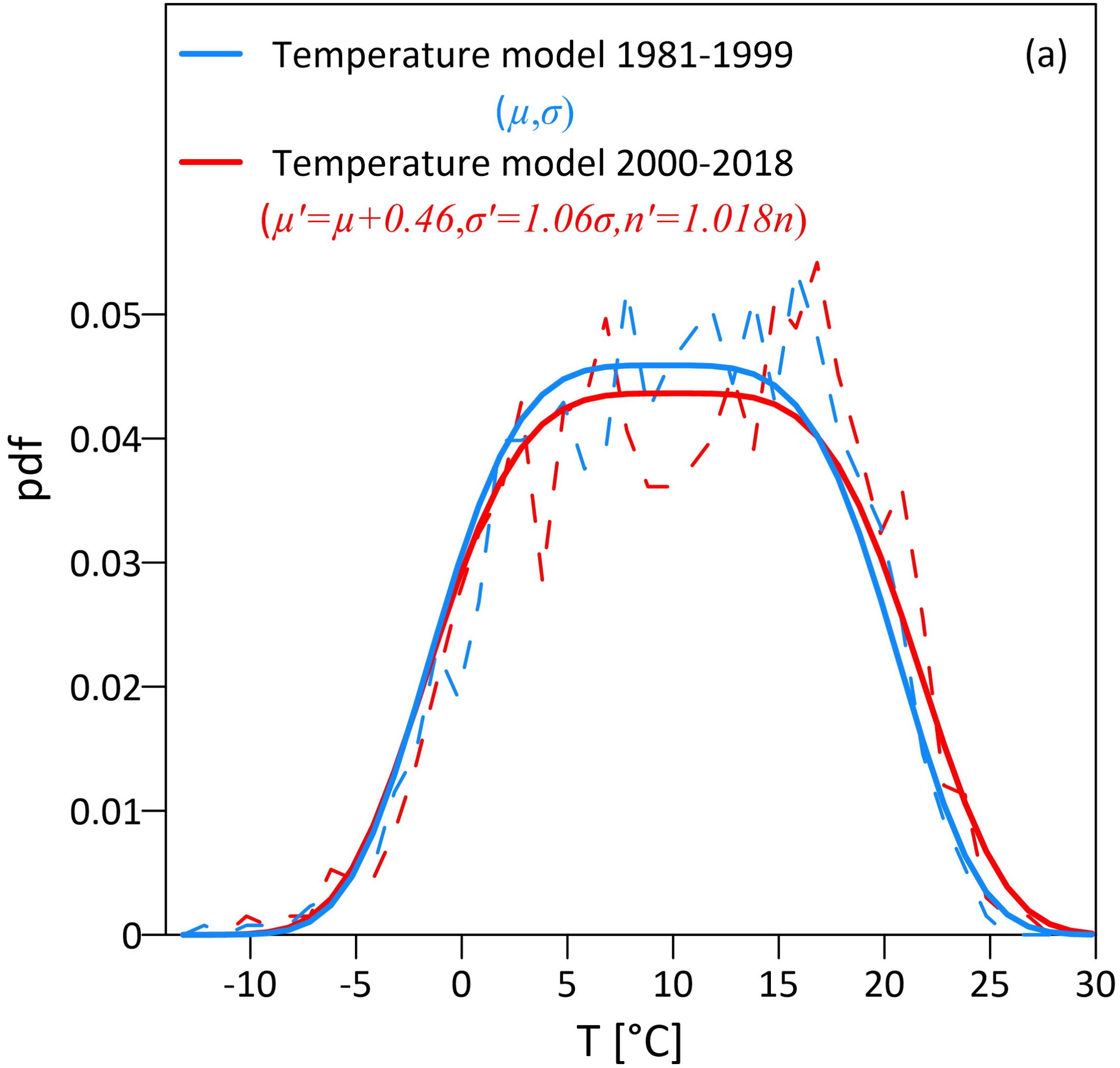
We assume physics remains unchanged
(magnitude model *W* invariant)

$$G_{\mathrm{TENAX}}(x) = \left(\int_{-\infty}^{+\infty} W(x;T) \cdot g(T)\, dT \right)^n$$

Future extremes will depend on the changes in temperature during the events
(change mean and variance of *g* according to model projections)



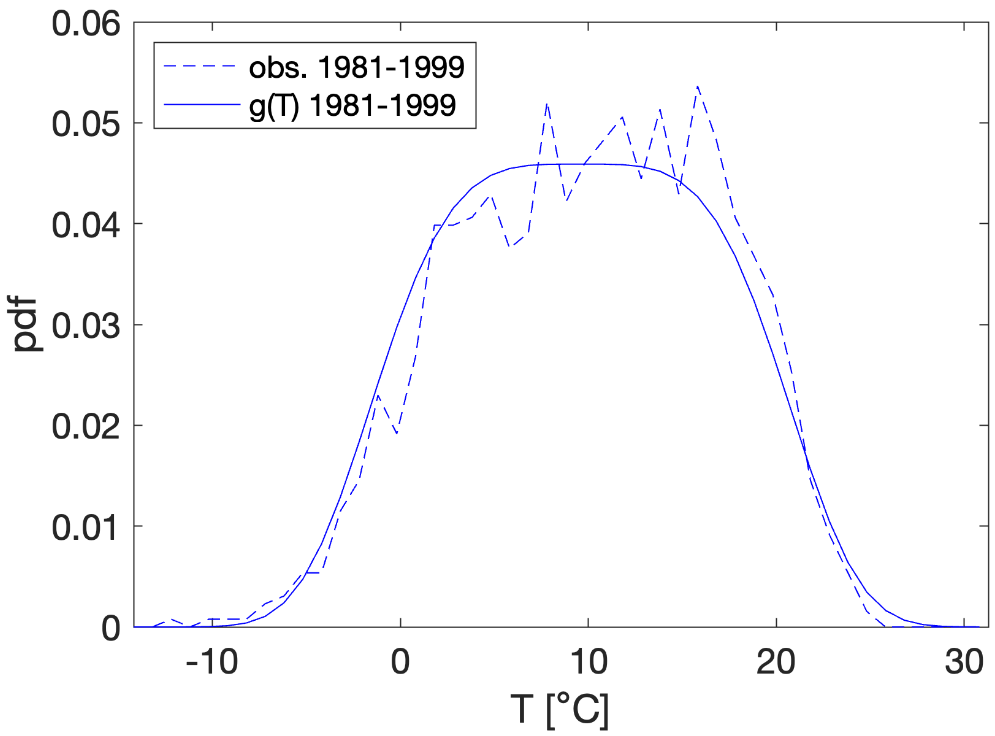
evaluating TENAX projections



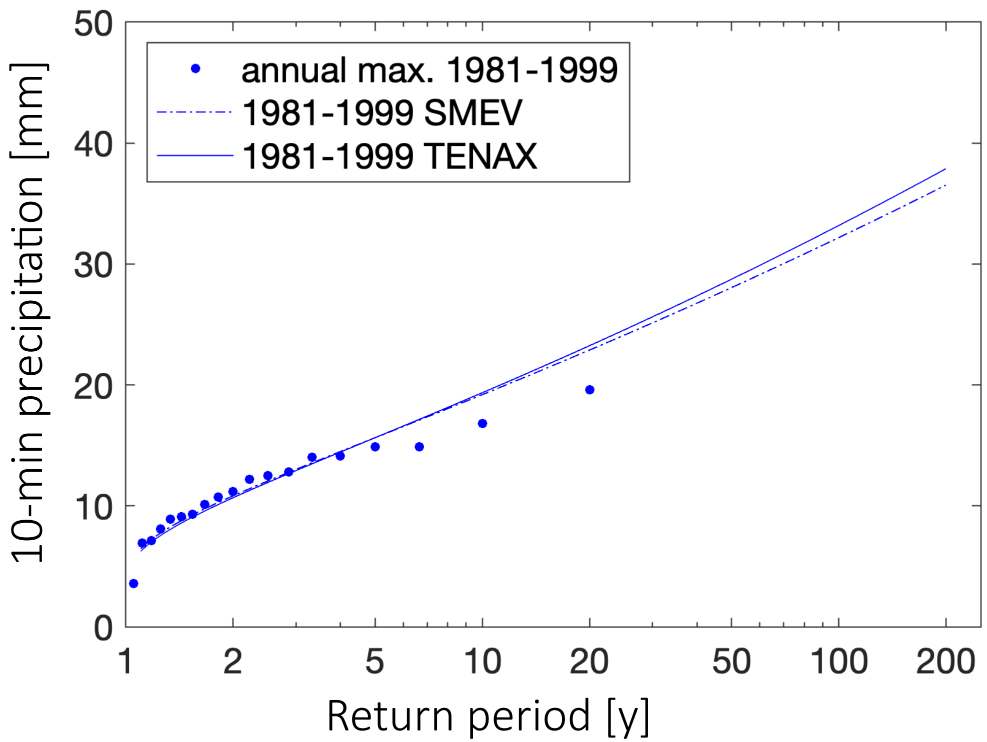
1. Split data into <u>two time slices of equal length</u> (1981-1999, 2000-2018)
2. <u>Estimate *W* from the first slice only</u> (contains information on the physics)
3. <u>Compute changes in mean and variance of *g*</u> from observations
4. Estimate return levels using <u>*W* estimated from the past and projected *g*</u>

evaluating TENAX projections

It's the end of 1999, we predict extremes for the next ~20 years…



Daily temperatures during the events



Frequency curves

evaluating TENAX projections

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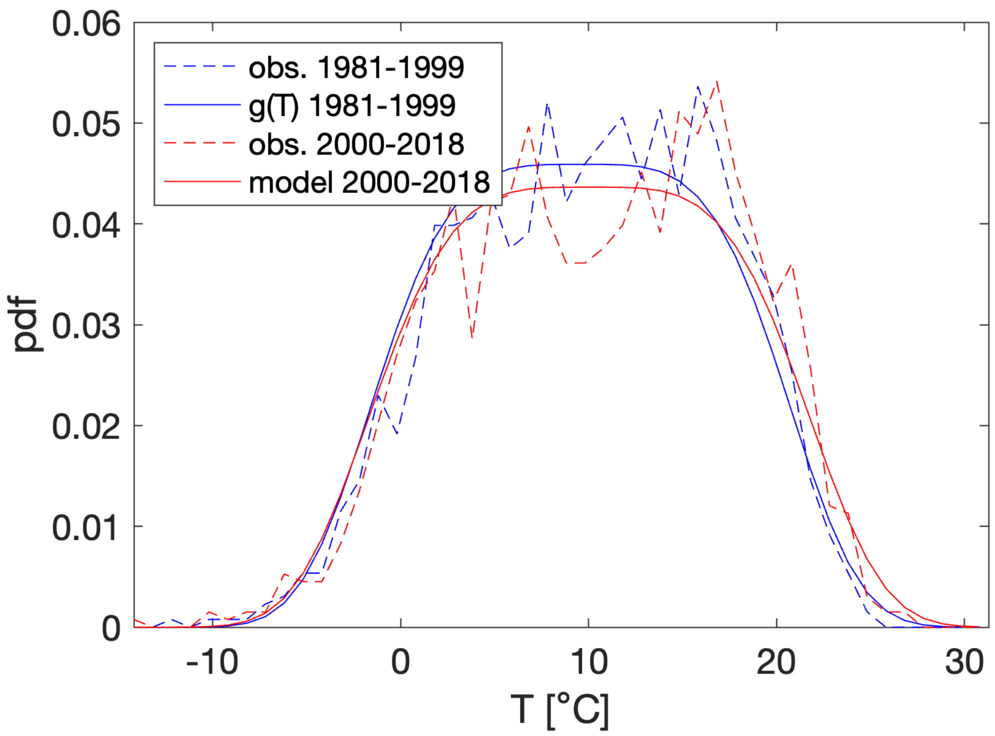

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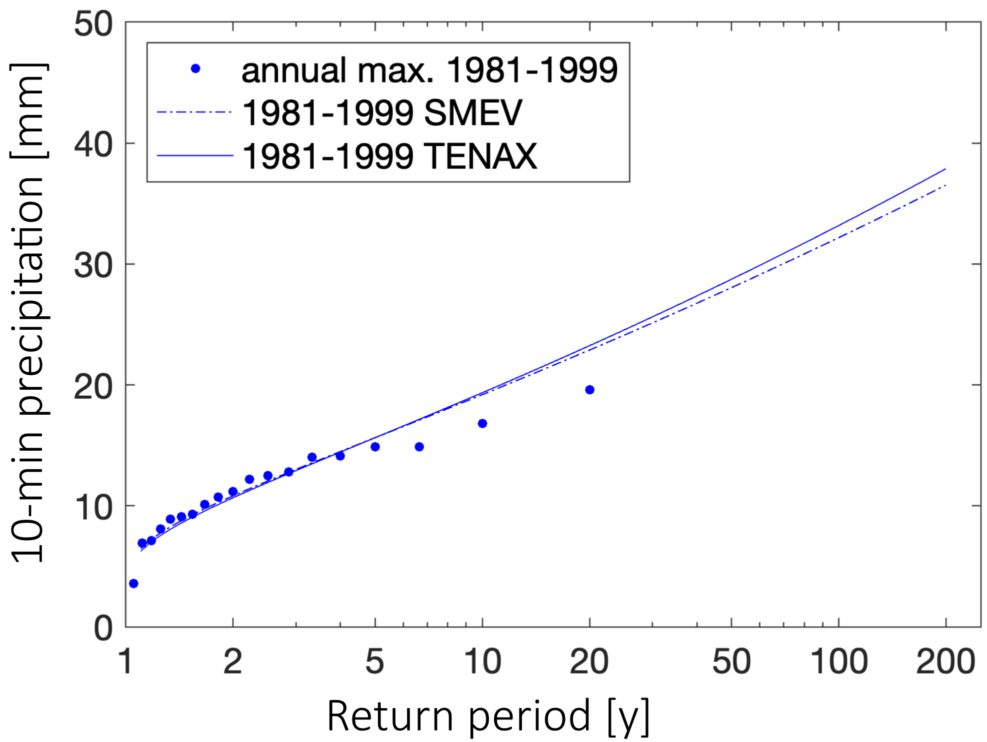

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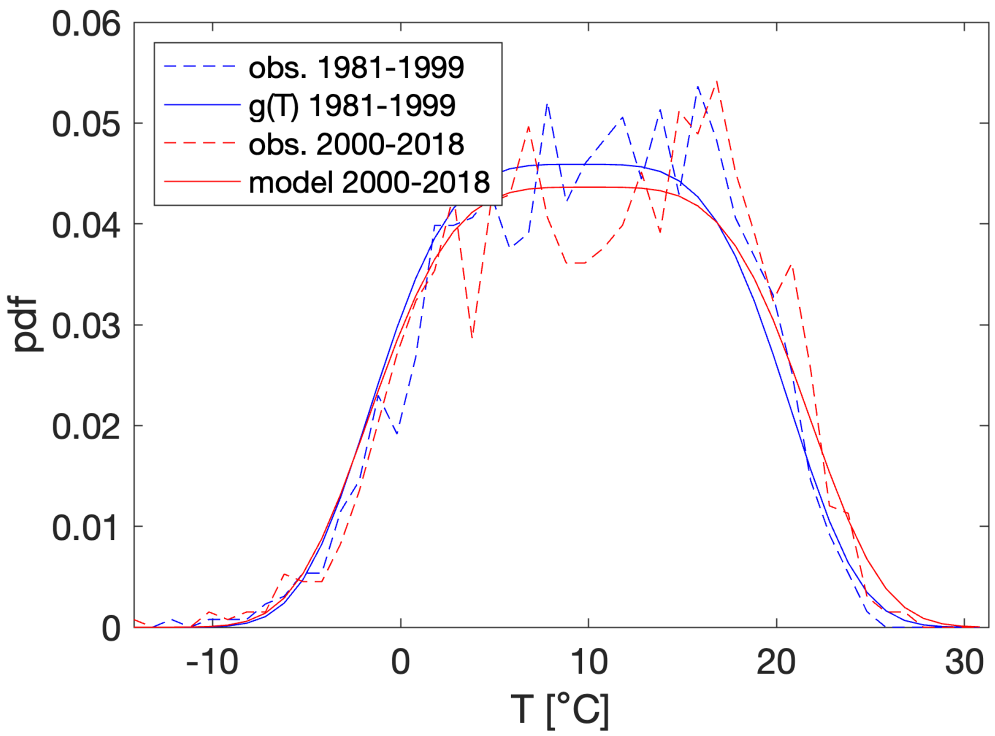

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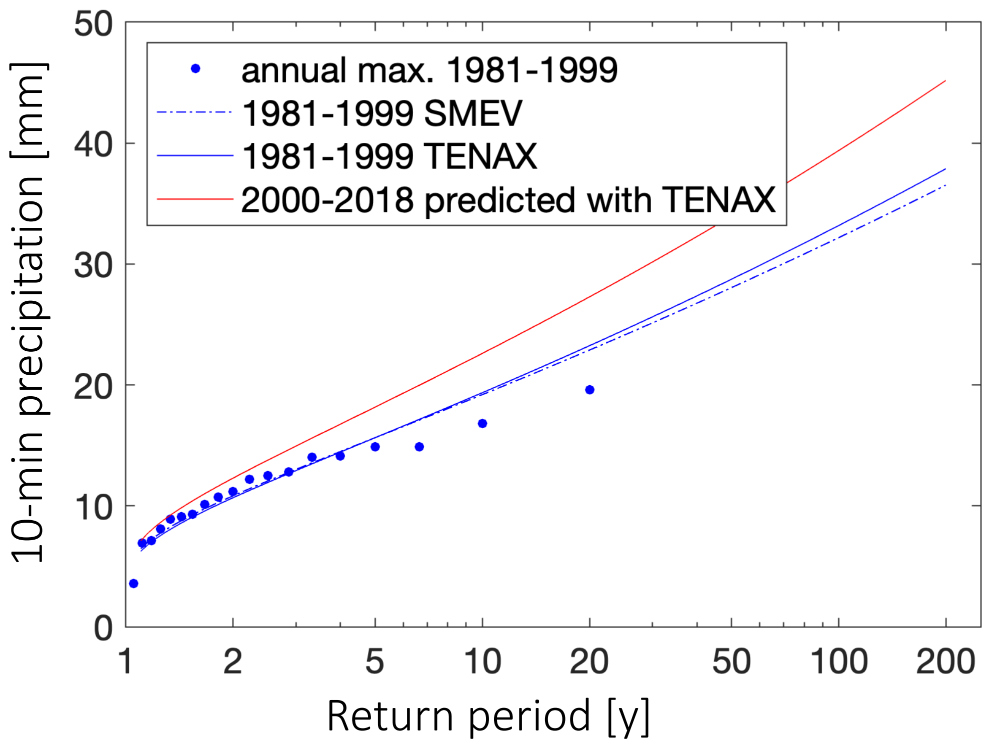

Frequency curves

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evaluating TENAX projections

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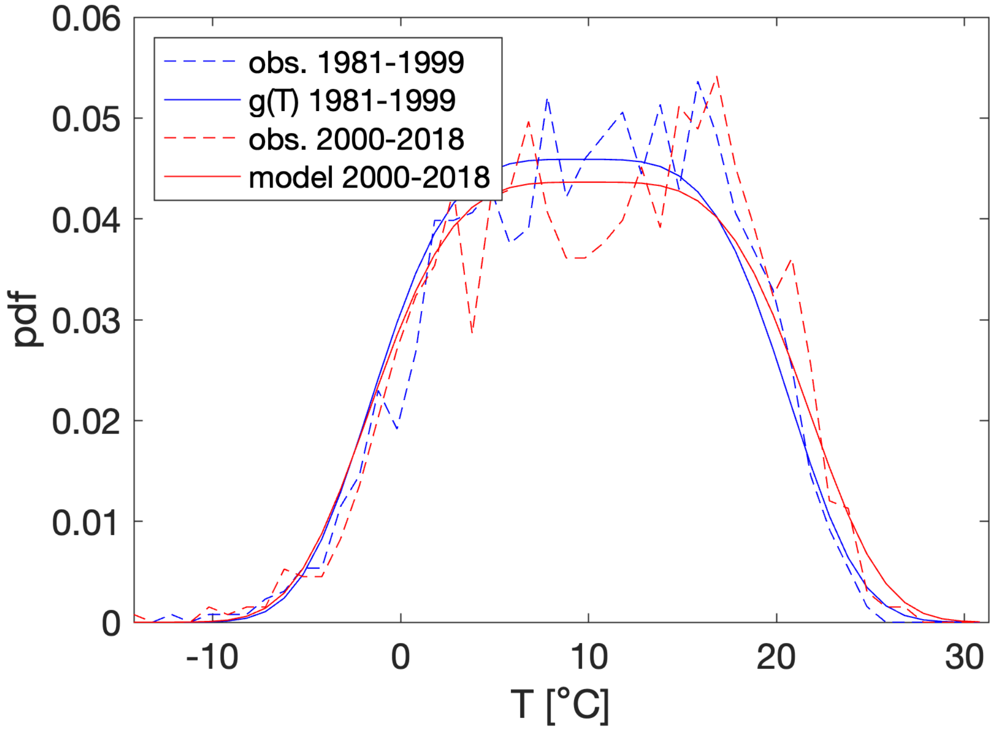
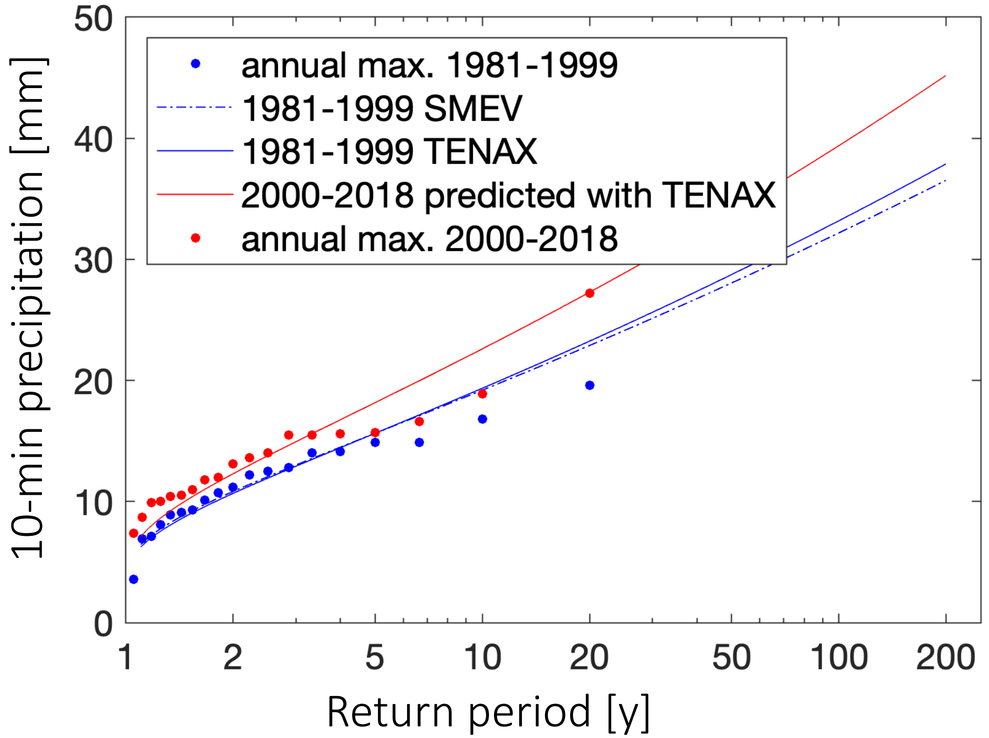


Daily temperatures during the events



Frequency curves

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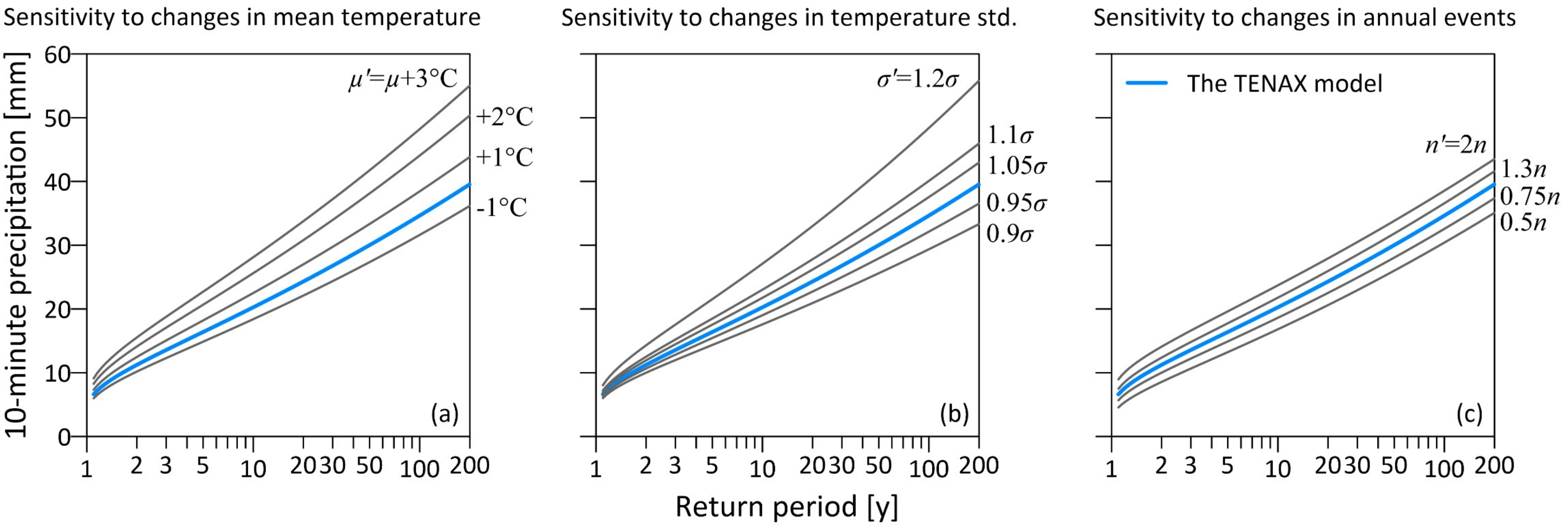
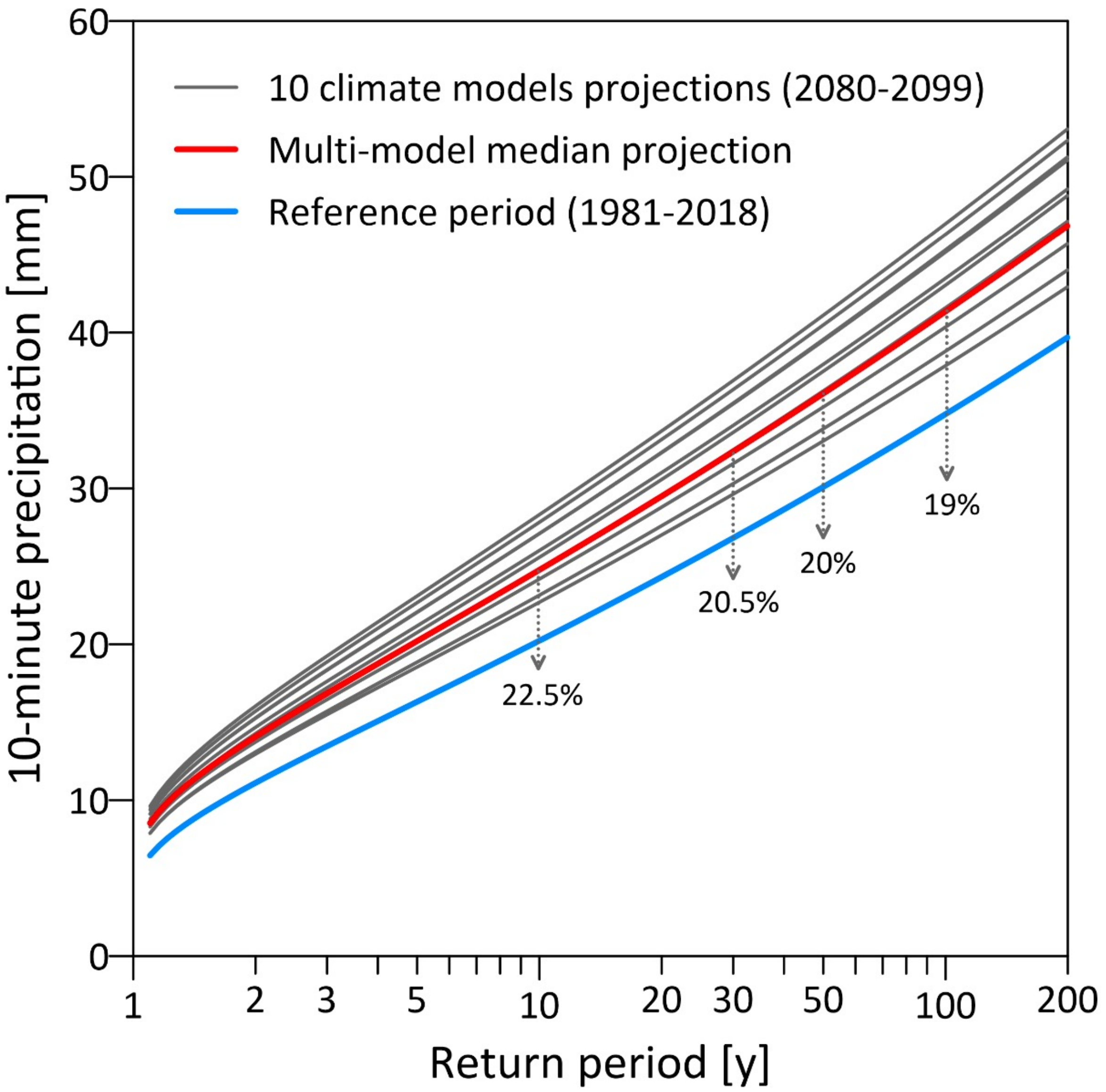
sensitivity to climate change



real-world application



Ensemble of 10 regional climate models

Changes in mean and variance of daily temperature during wet days

Changes in annual number of wet days

Projected future return levels

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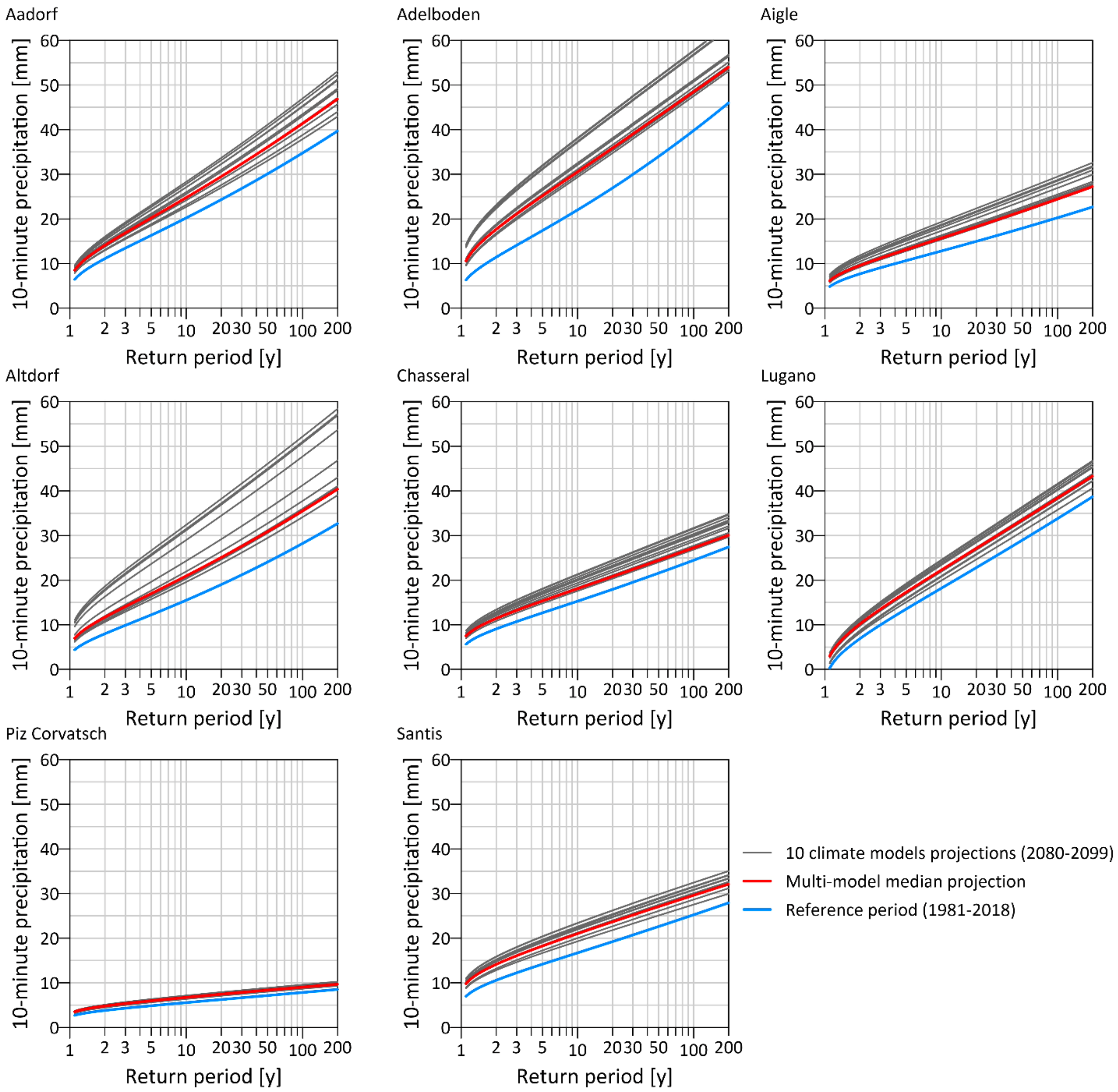
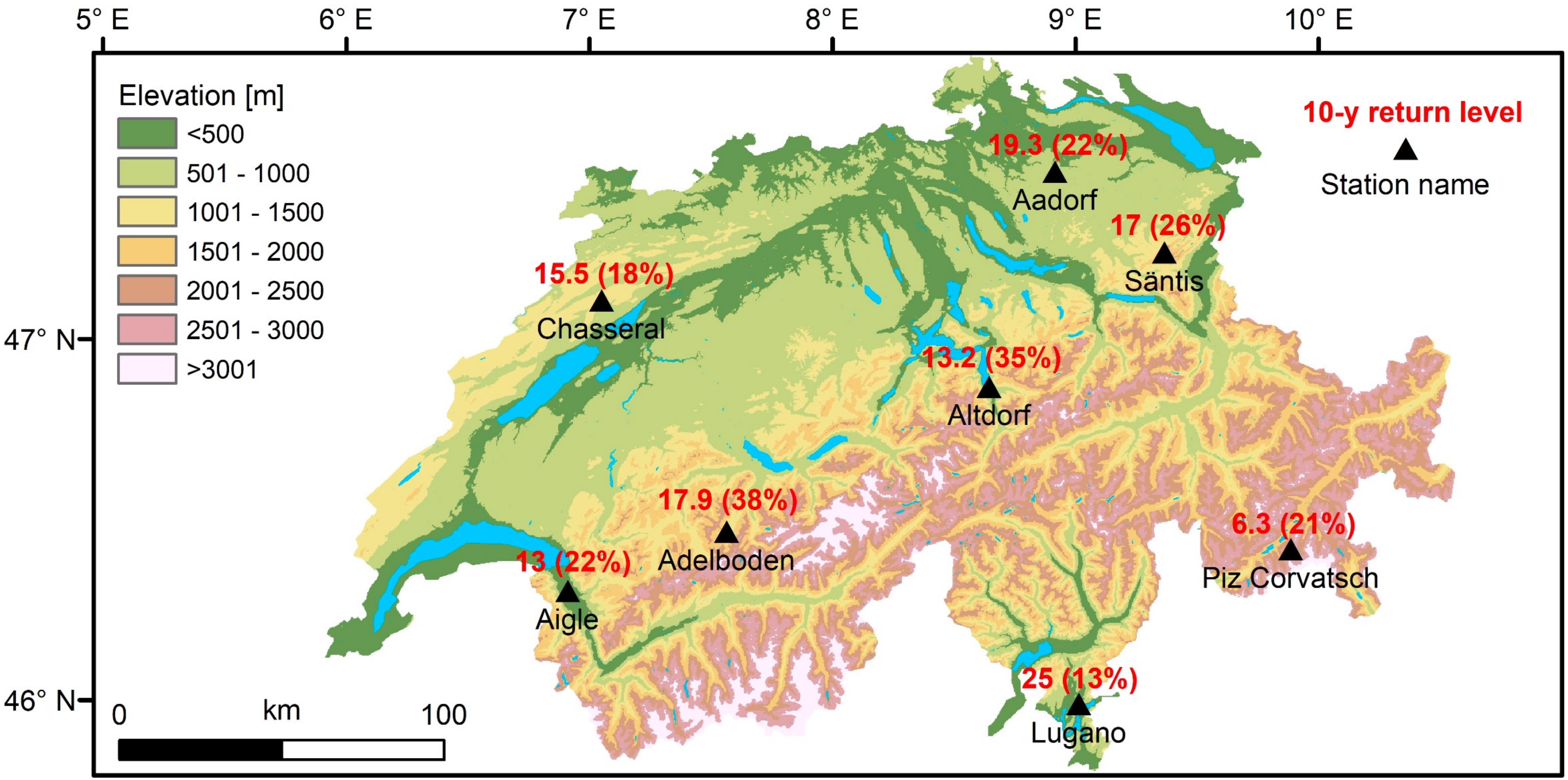
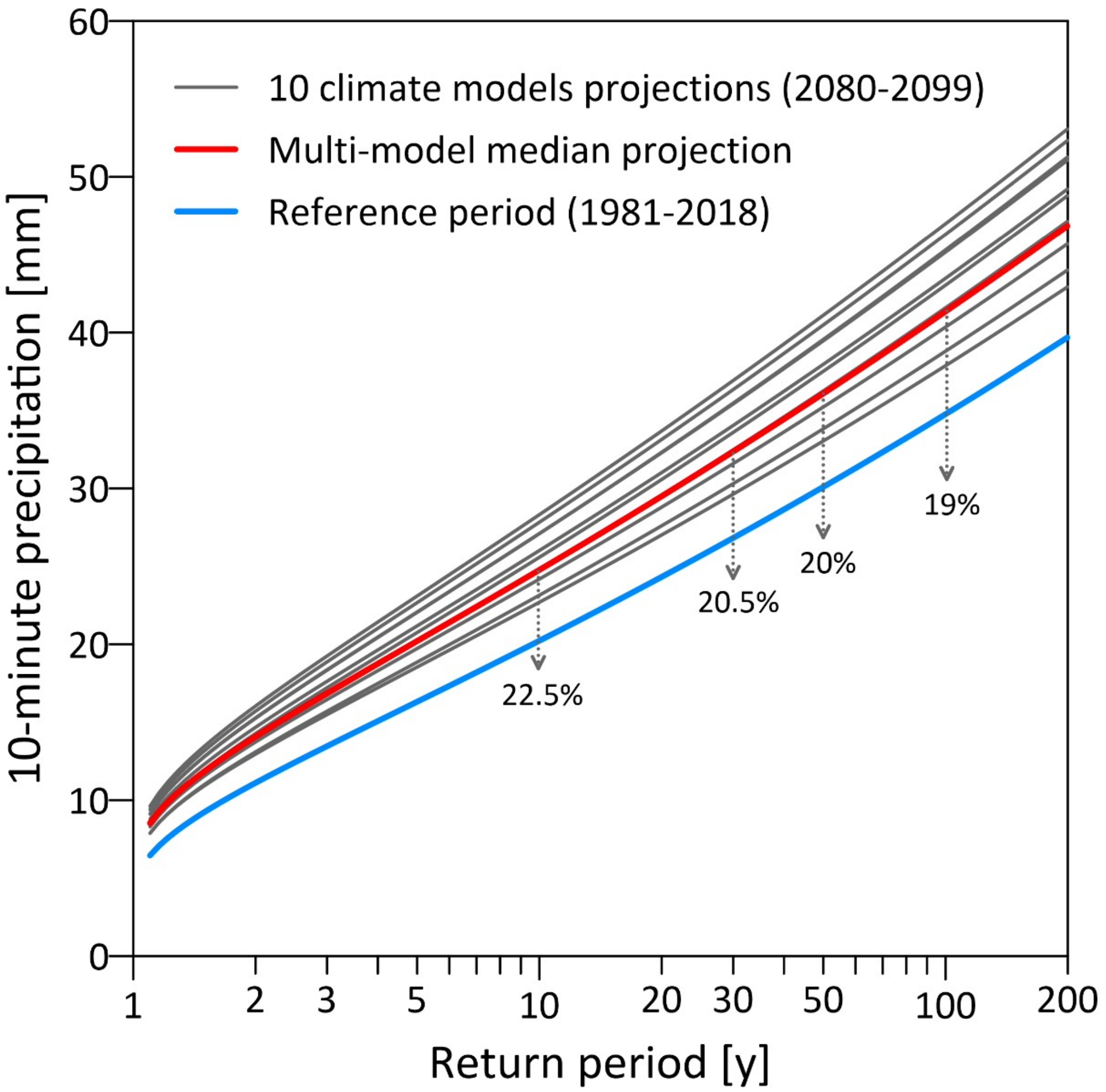
projections



real-world application



real-world application



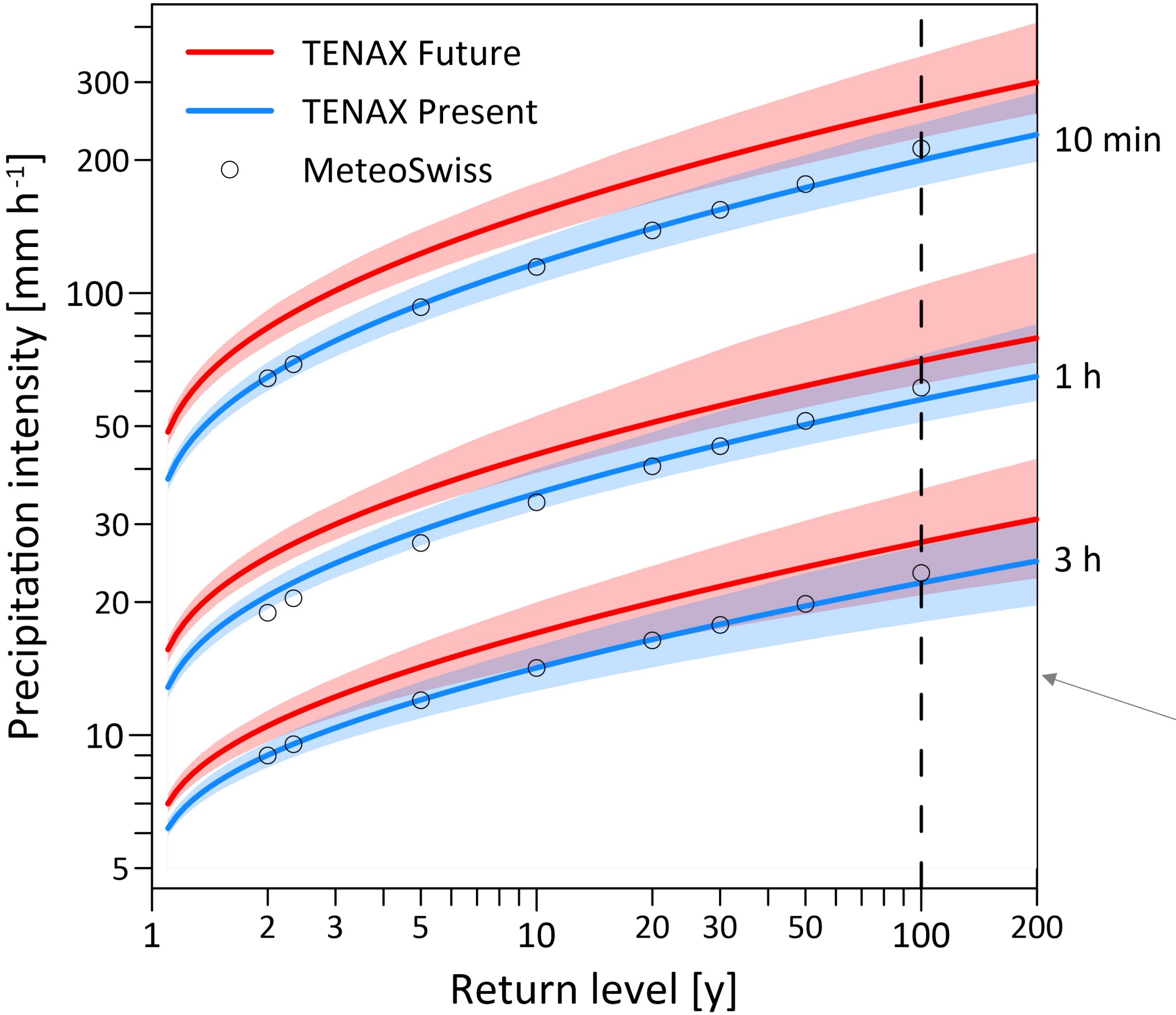
Ensemble of 10 regional climate models

Changes in mean and variance of daily temperature during wet days

Changes in annual number of wet days

Projected future return levels for durations of 10 minutes, 1 hour and 3 hours

real-world application



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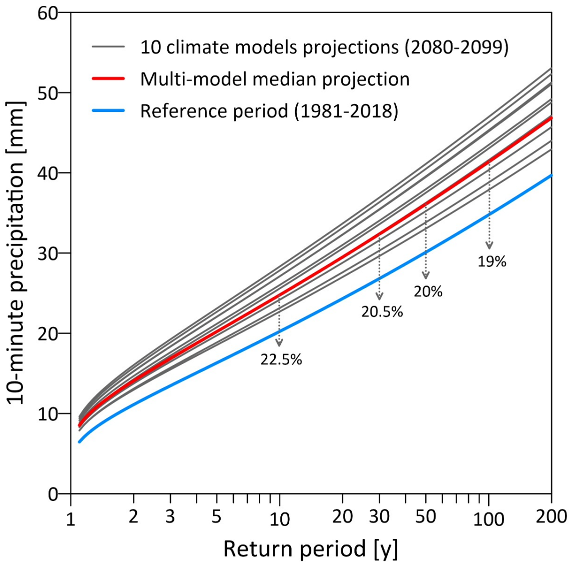
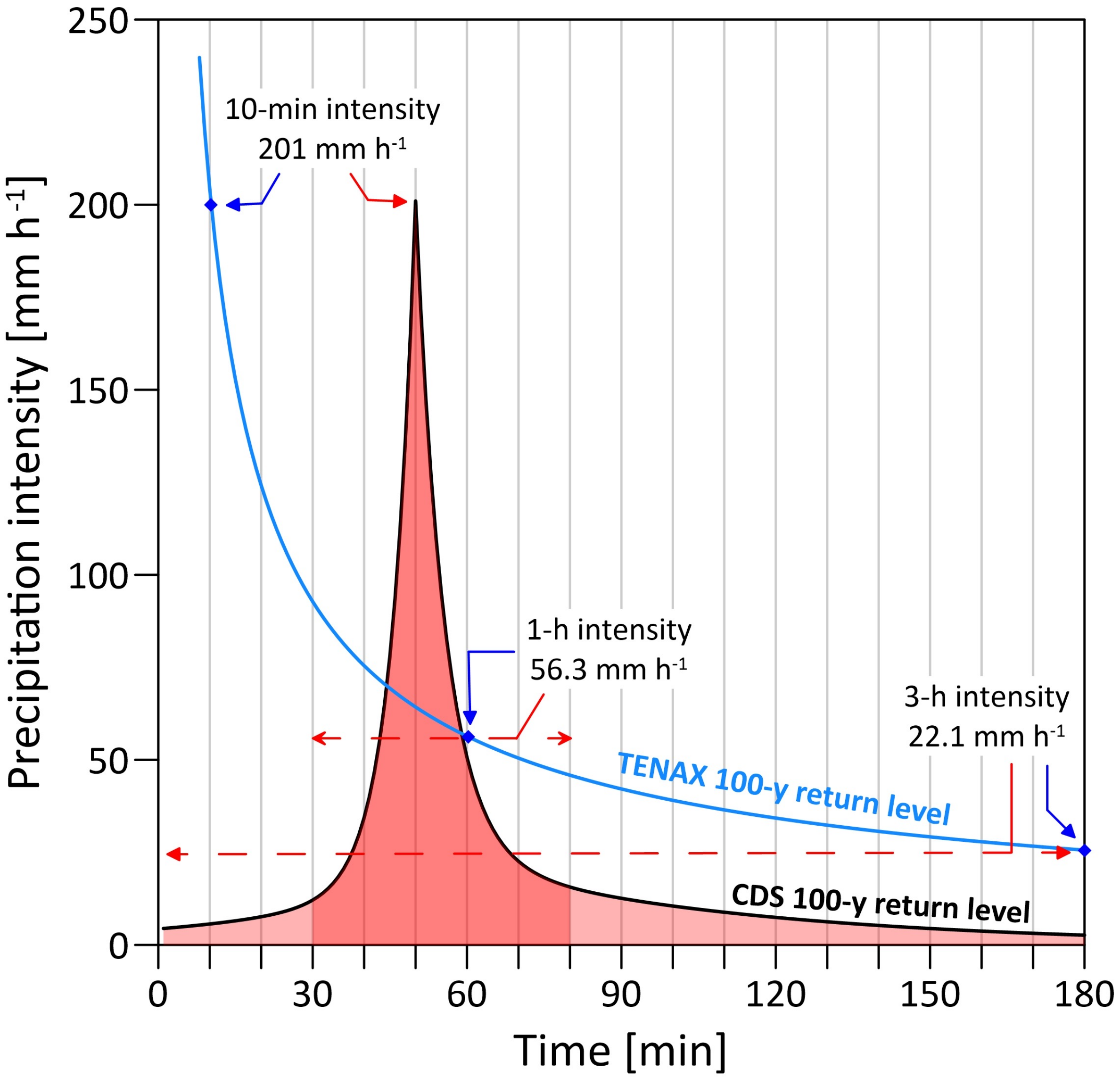
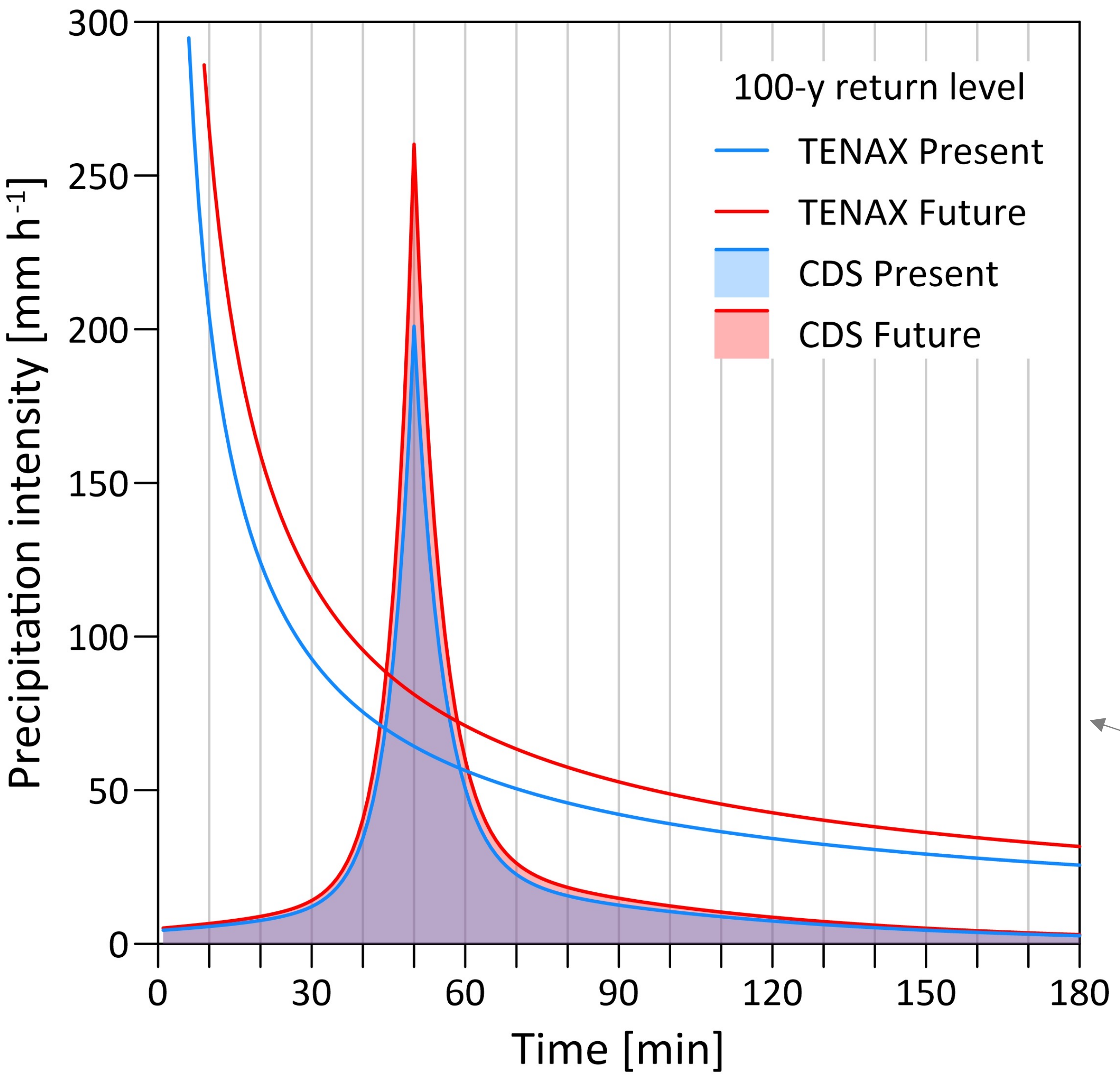


real-world application

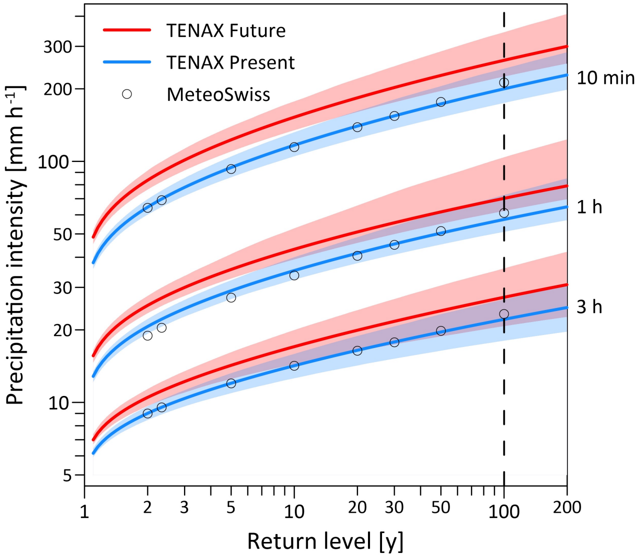
Chicago Design Storm (CDS)



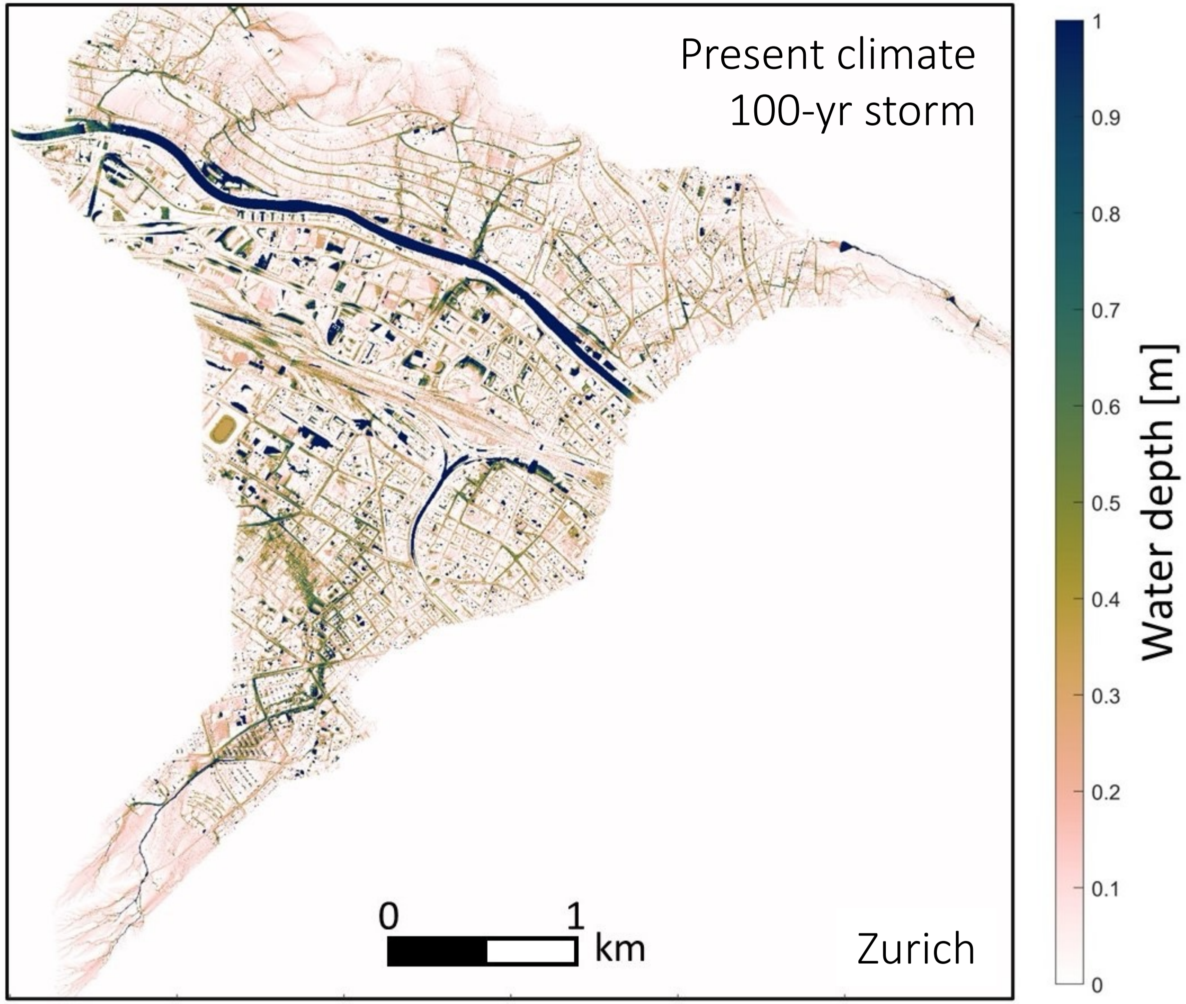
real-world application



Present and future <u>100-year design storms</u> for the city of Zurich



real-world application

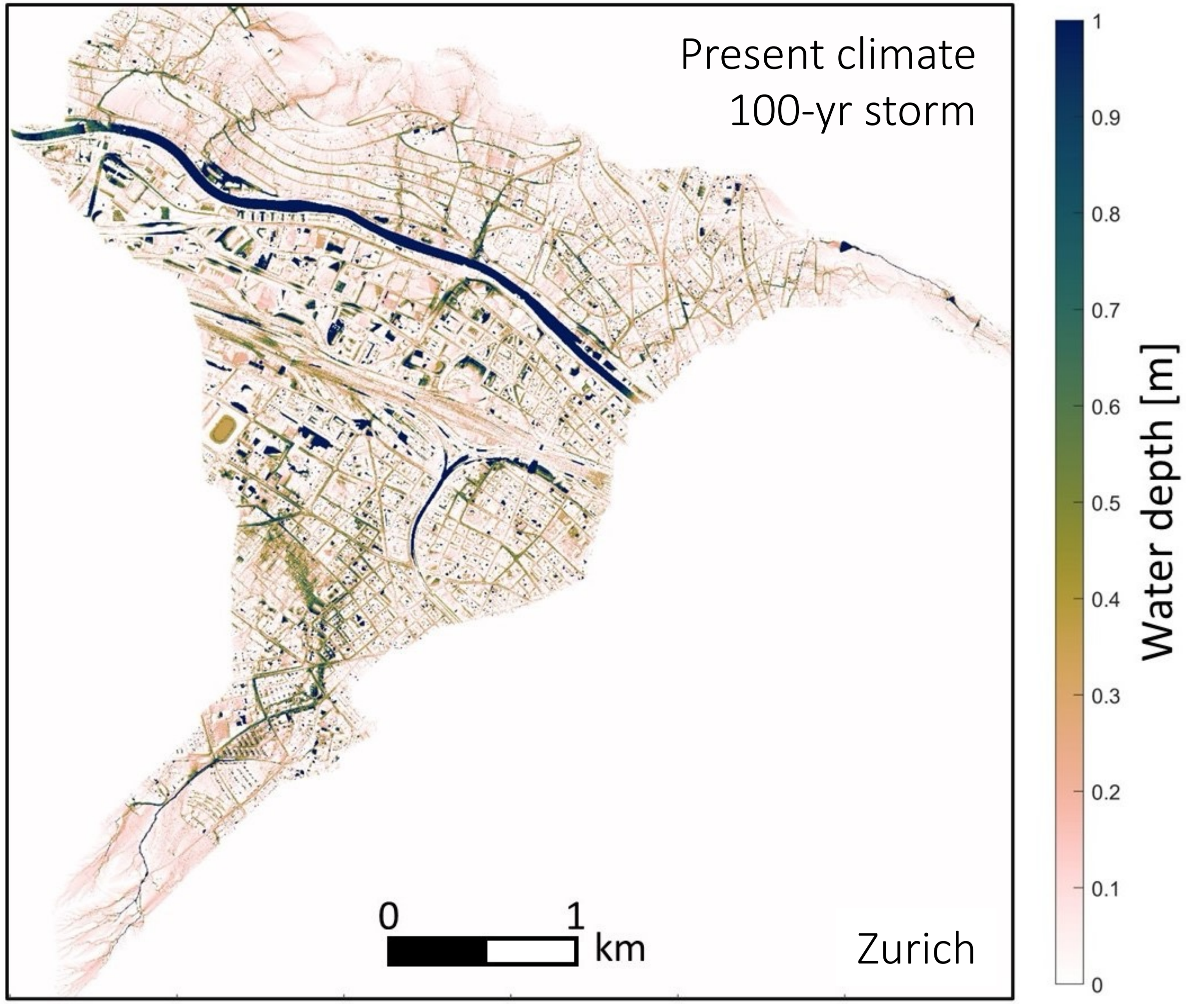


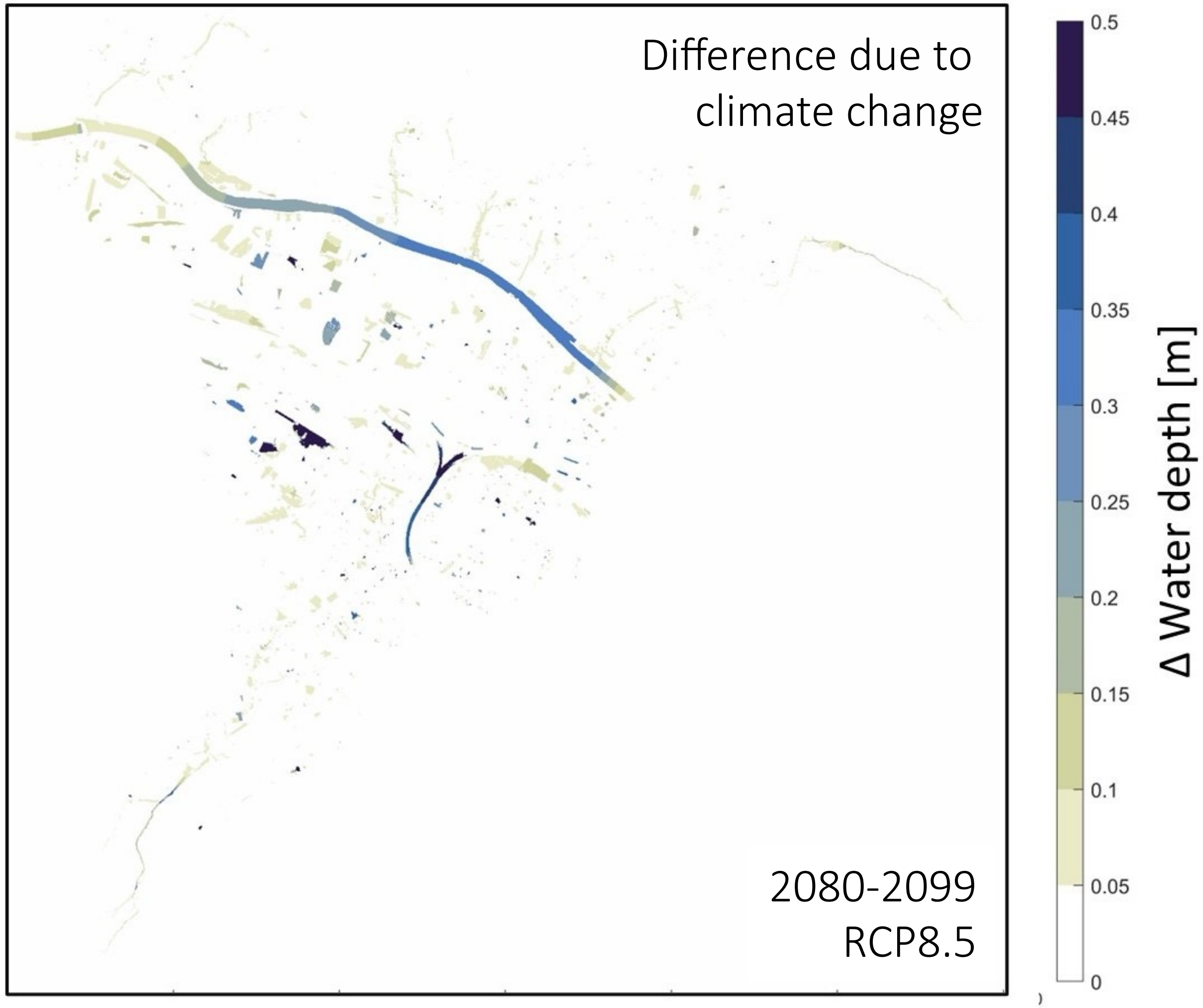
Present and future return levels (TENAX)
(10 models ensemble mean)

Present and future 100-year design storms (TENAX-CDS)

Urban inundation (CAFlood)

real-world application





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thanks to all the colleagues that collaborated on this project

Proiezioni di precipitazioni estreme sub-orarie sulla base delle temperature future

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** Equal contribution*

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thank you

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More info in the published paper: https://hess.copernicus.org/articles/28/375/2024/

Codes are freely available:

- TENAX: https://doi.org/10.5281/zenodo.8345905
- TENAX-CDS: https://doi.org/10.5281/zenodo.10491542

Paper

TENAX TENAX-CDS

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