A physics-based statistical model to predict sub-hourly extreme precipitation intensification based on temperature shifts

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Background and objectives

For climate change adaptation and resilience, we critically need information on future sub-hourly precipitation return levels

Current approaches are insufficient:

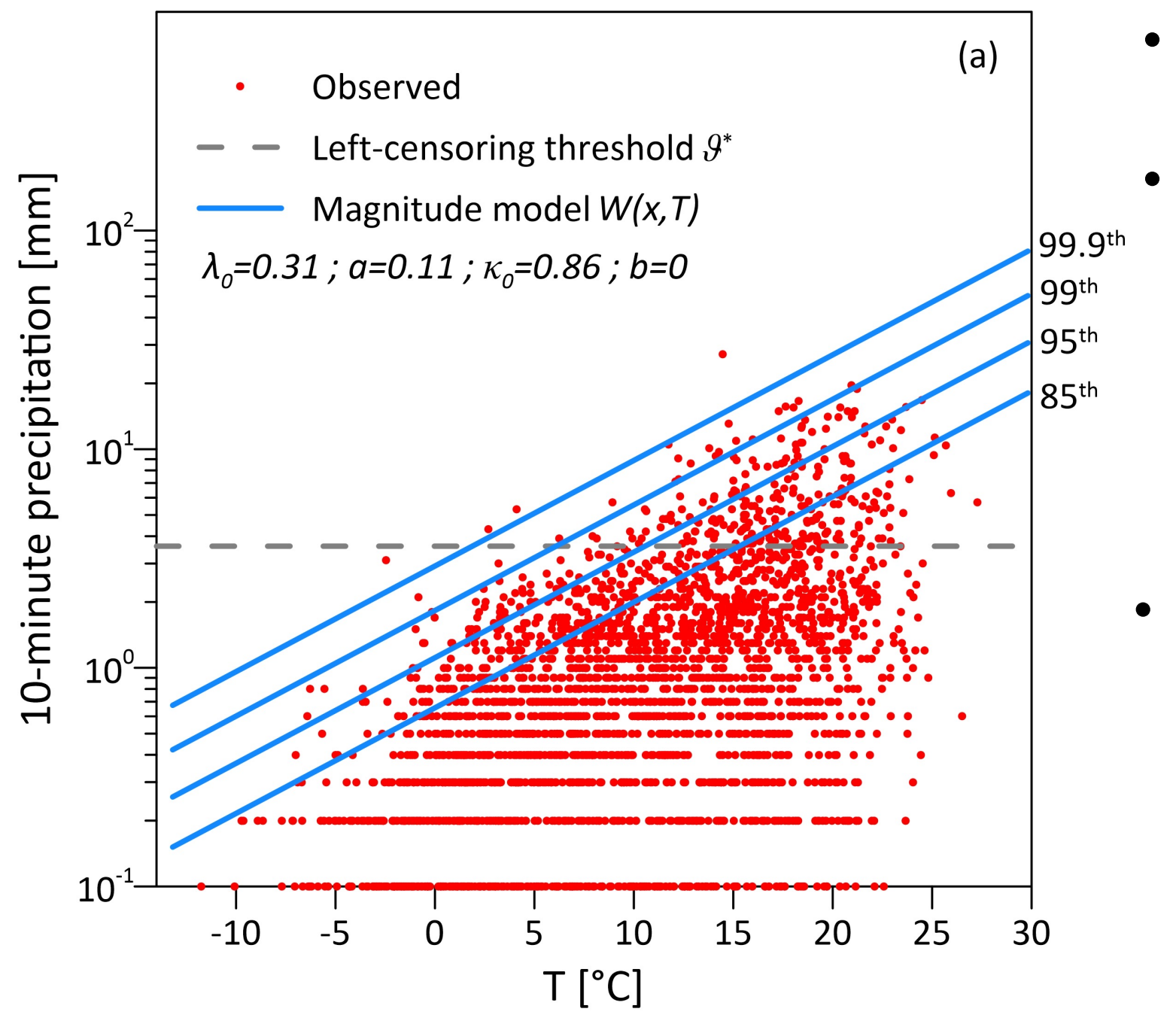
- limited availability of convection-permitting model simulations (capable of simulating sub-hourly precipitation adequately)
- frequency analysis methods are merely data driven and do not consider the physics behind precipitation processes

We present TENAX: a new statistical model to predict future sub-hourly return levels

- ✓ Physically consistent
- ✓ Robust – based on variables well simulated by climate models
- ✓ Easy to use – also for practitioners and end users

- TENAX brings together thermodynamic theory and statistics
- TENAX reconciles extreme precipitation-temperature scaling rates with extreme precipitation frequency analysis

TEmperature-dependent Non-Asymptotic model for eXtreme return levels (TENAX)



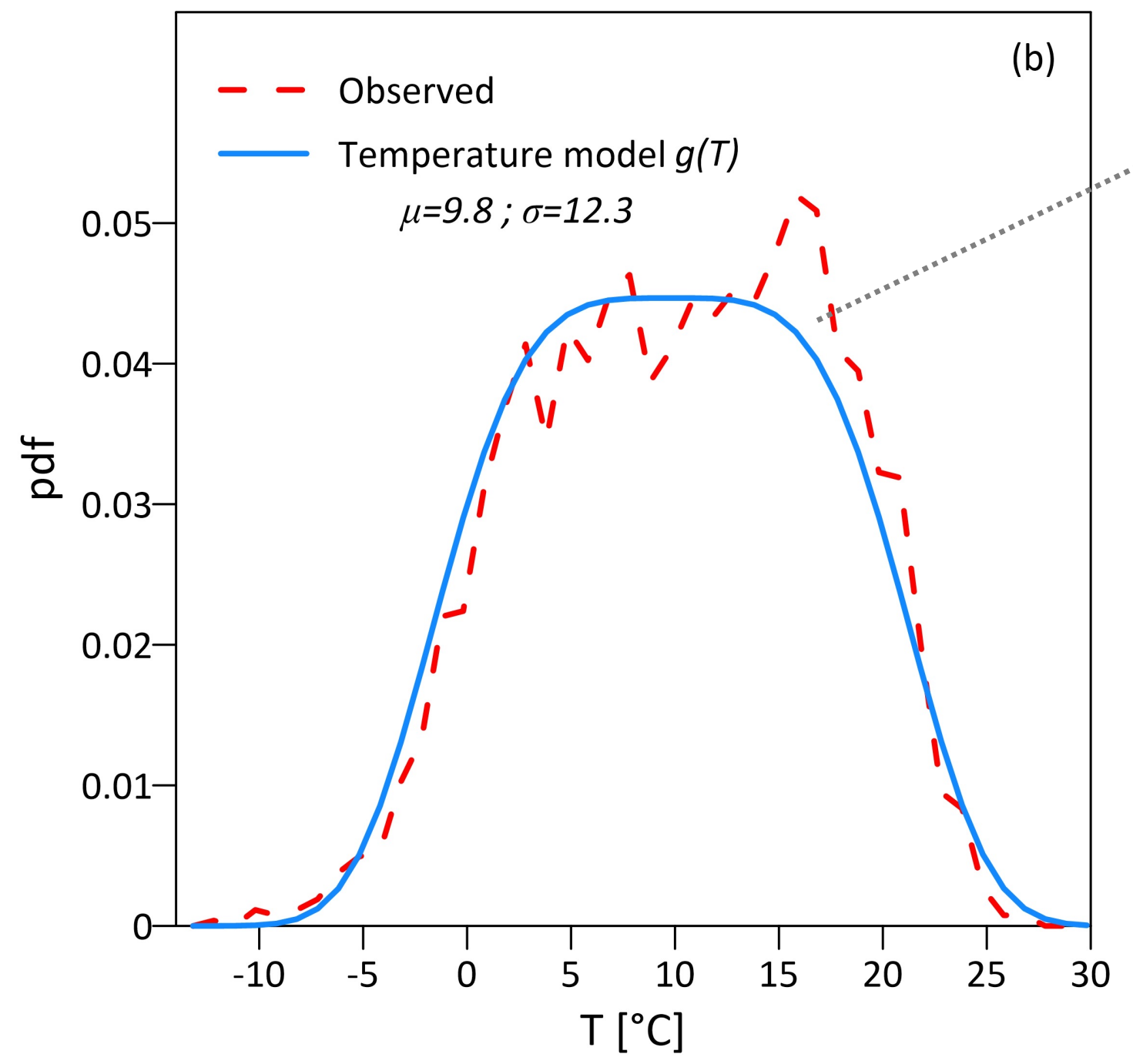
- Non-stationary Weibull model for the exceedance probability of extreme intensities as a function of T
- Contains information on the physics of the processes at temperature T

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

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

- Emerging statistics of extremes will depend on how temperature is sampled during events

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



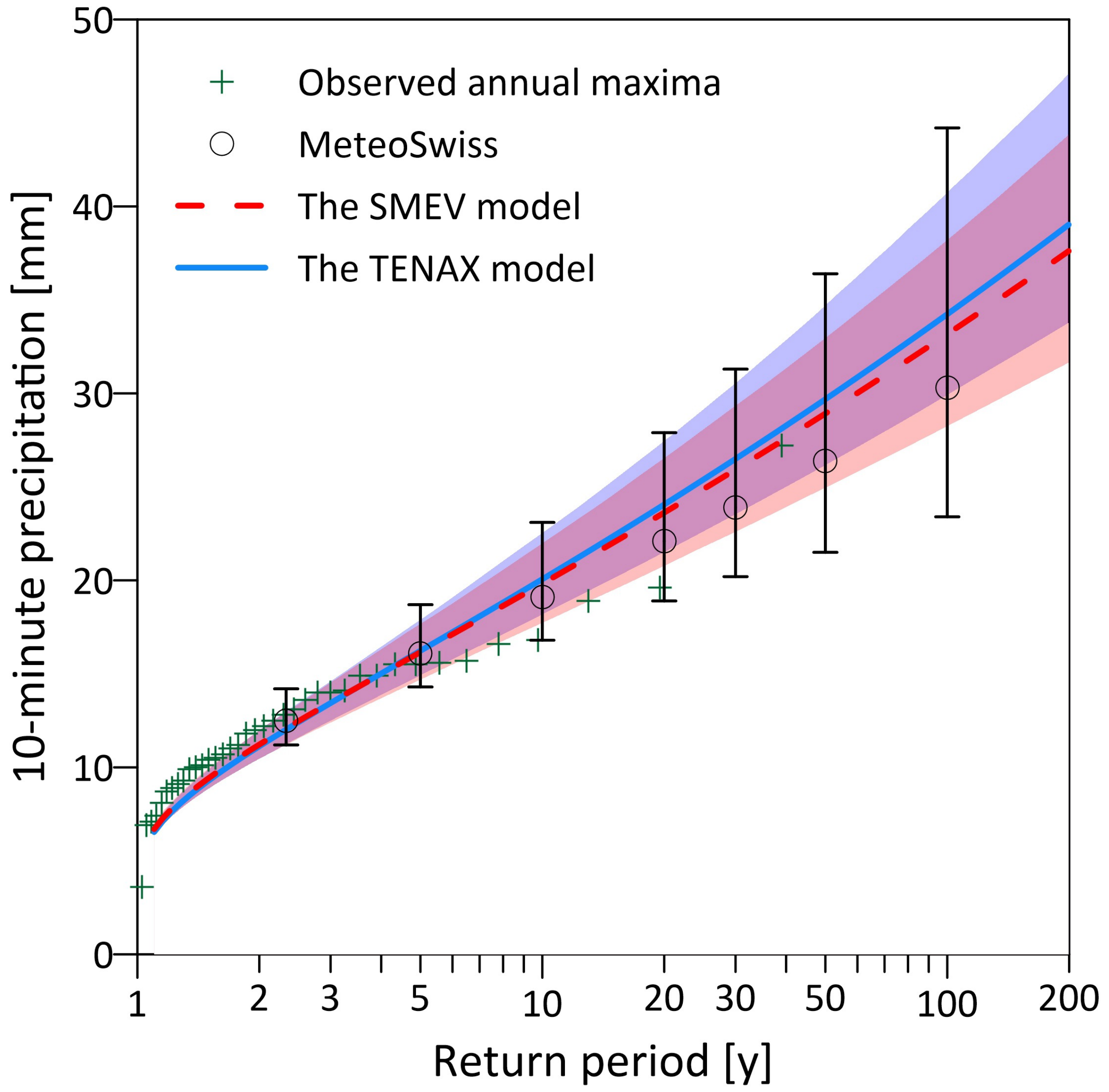
Return levels are estimated combining magnitude and temperature models:

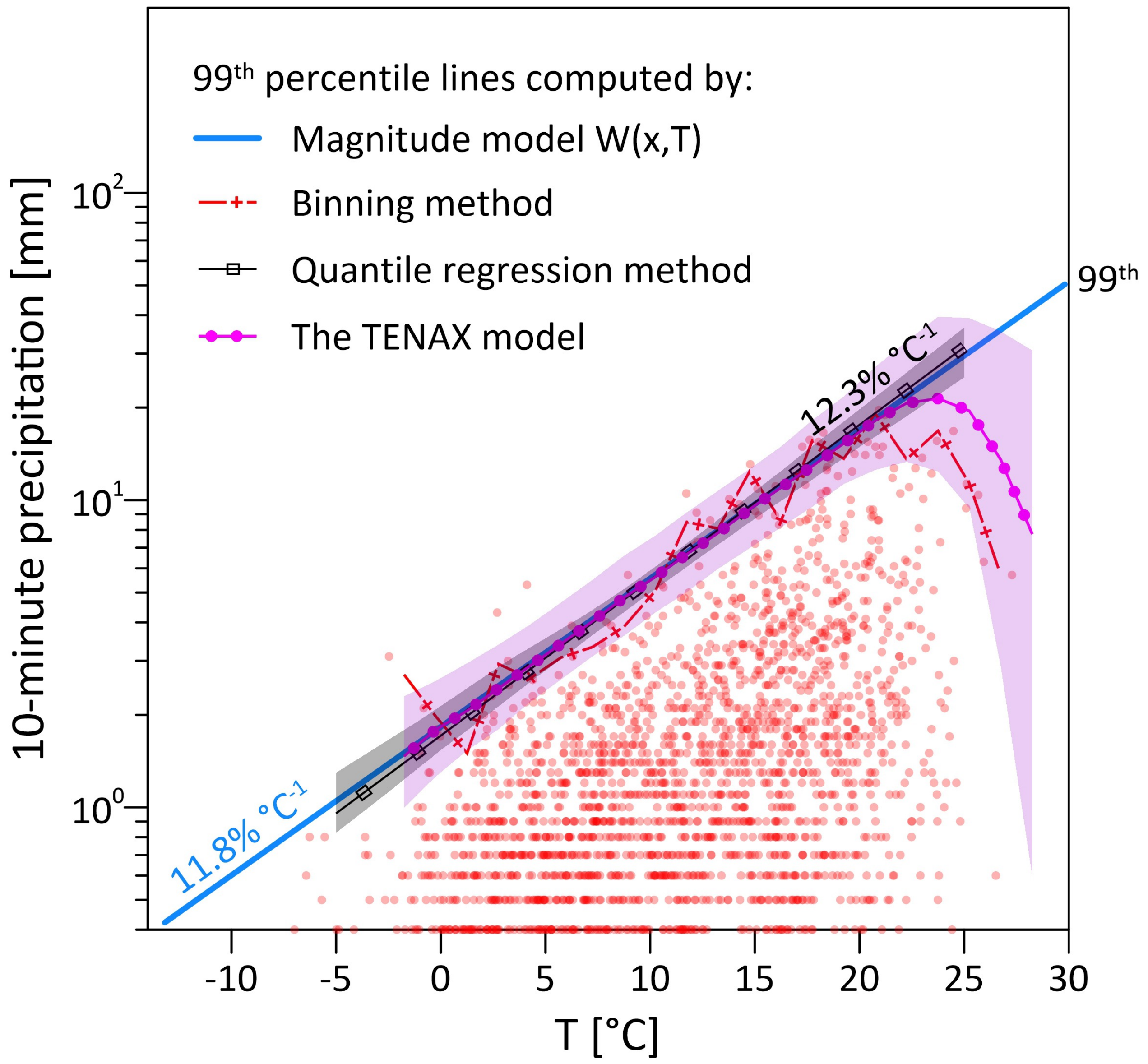
maxima from n-sized samples of F(x): $G(x) = F(x)^n$

$$G_{\mathrm{TENAX}}(x) = \underbrace{\left(\int_{-\infty}^{+\infty} W(x;T)\cdot g(T)\,dT\right)^n}_{\text{total probability theorem}} \simeq \underbrace{\left(\frac{1}{N}\sum_{i=1}^{N} W(x;T_i)\right)^n}_{\text{Monte Carlo approximation}}$$

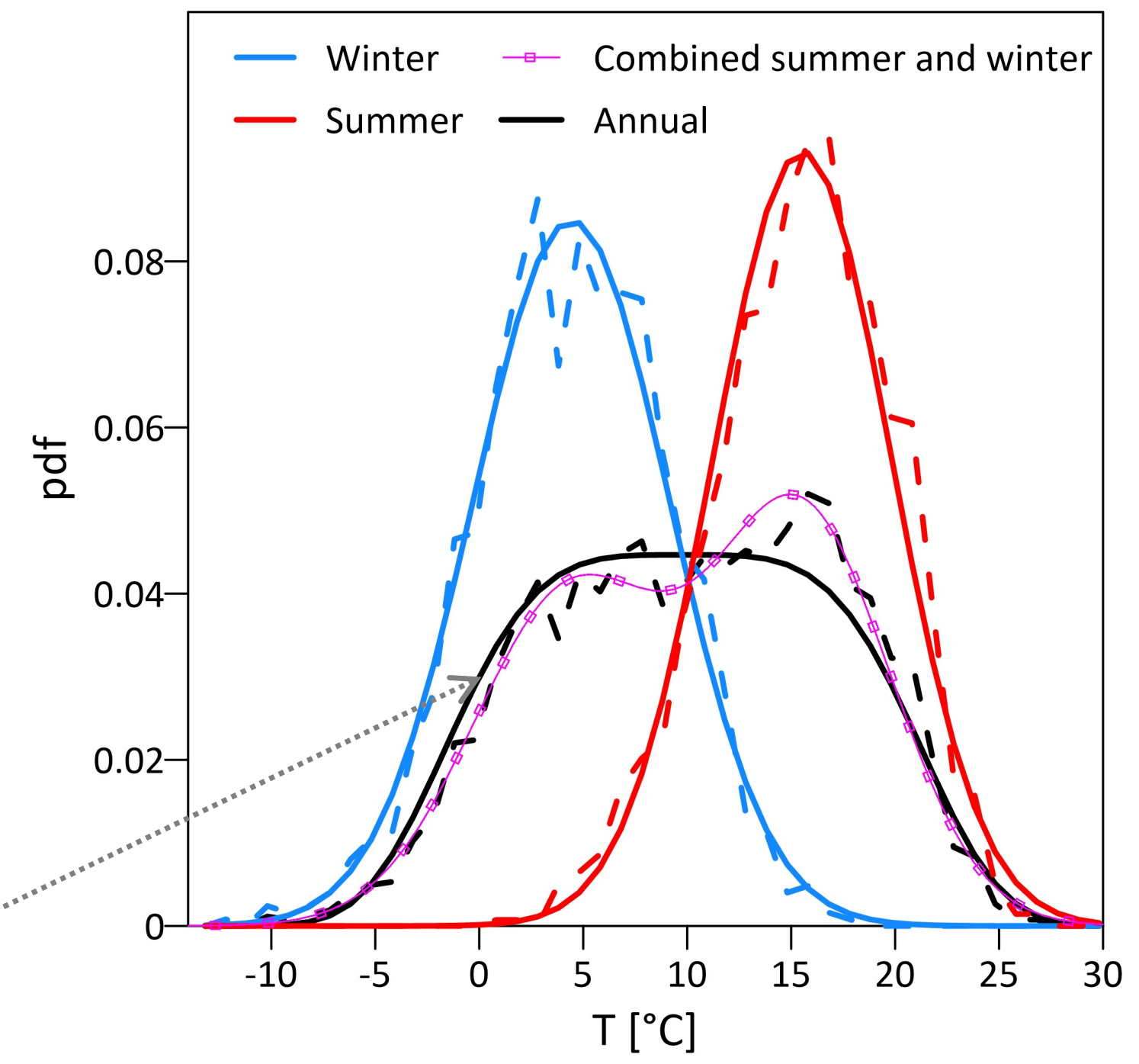
TENAX explains known properties of extreme precipitation

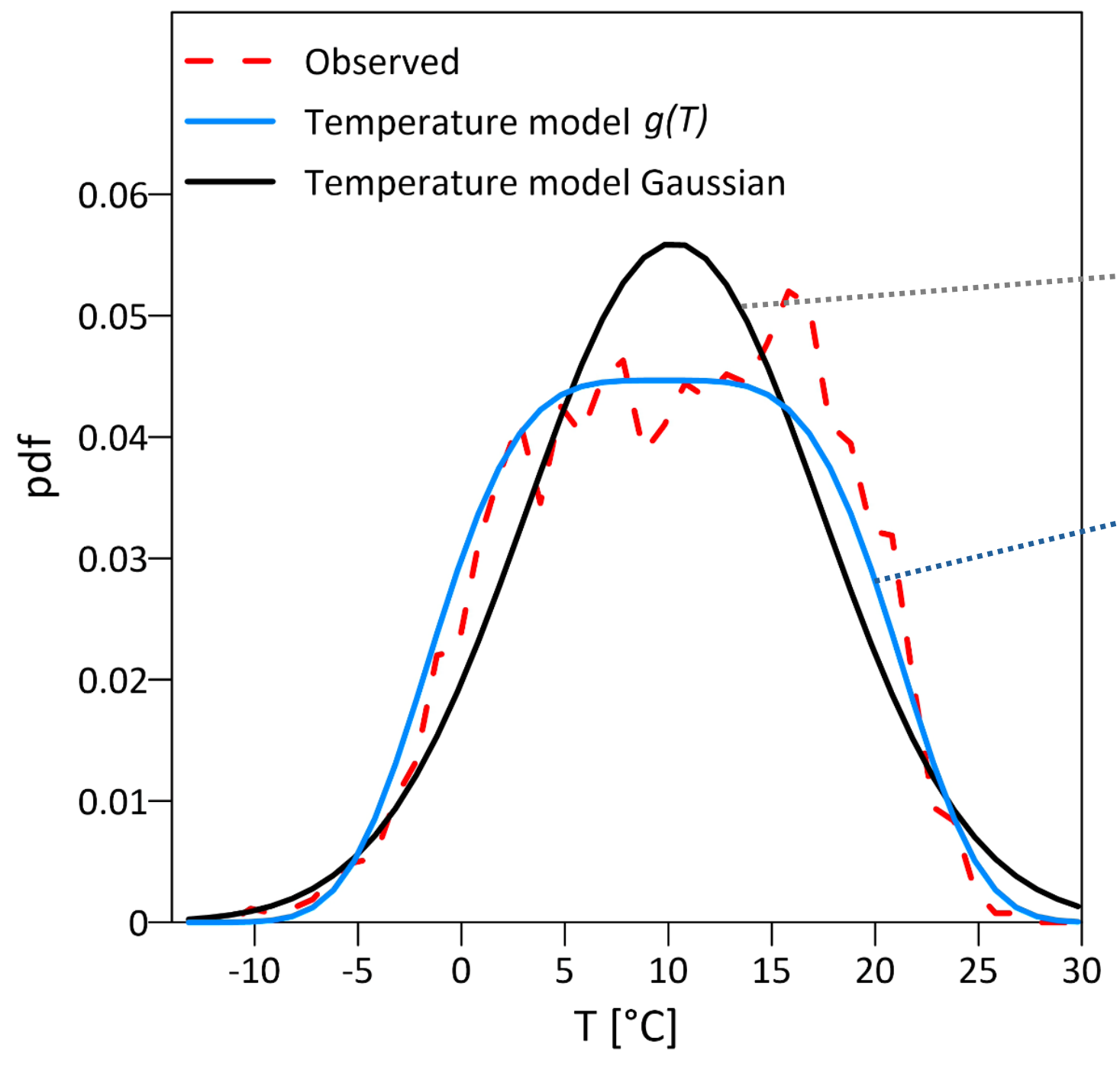
- Extreme precipitation-temperature scaling rate
- Breaking of the scaling relation at high temperatures (hook structure) is due to sharp decrease in probability of occurrence of precipitation events at high temperatures – right tail of the temperature model

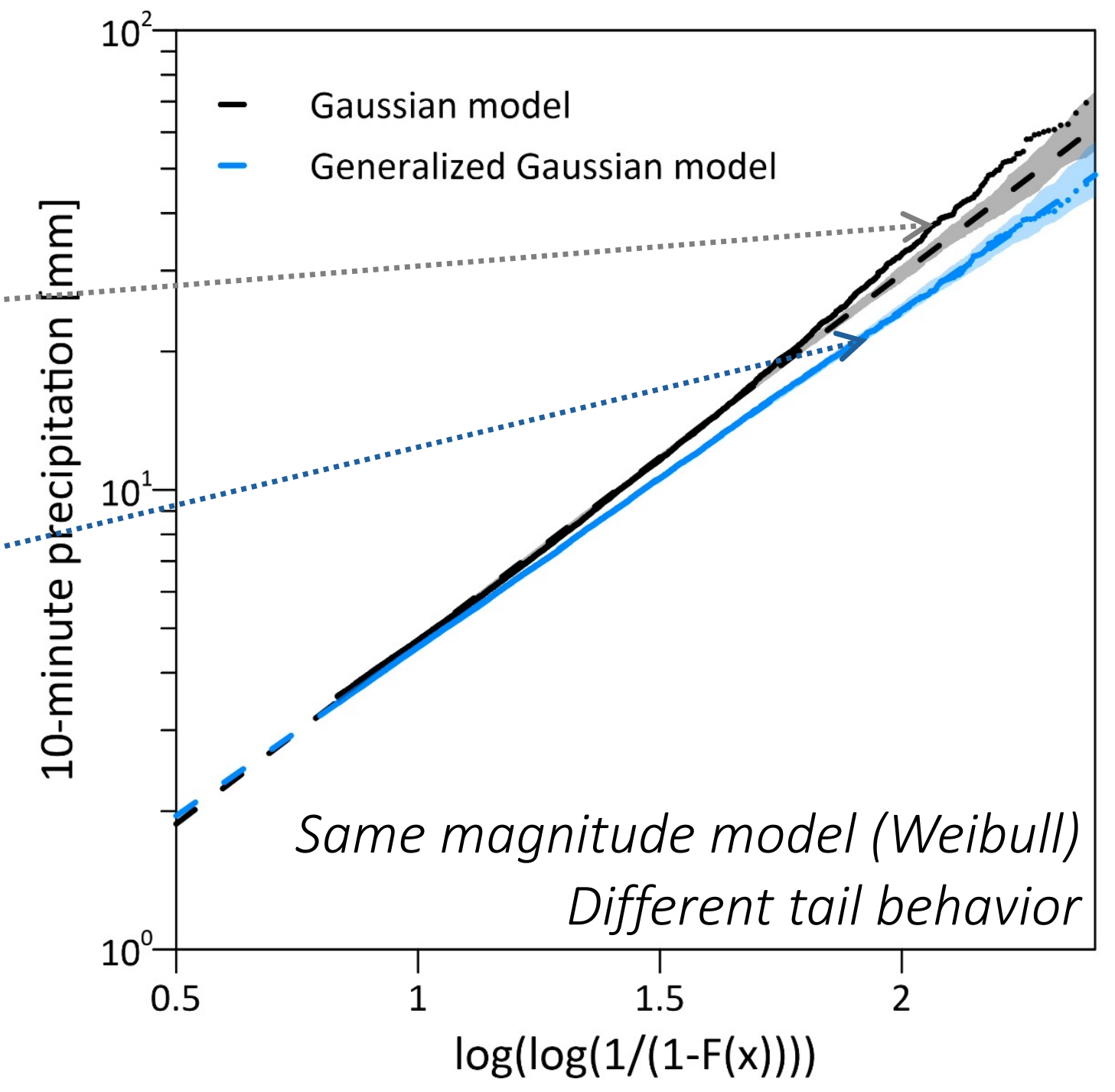




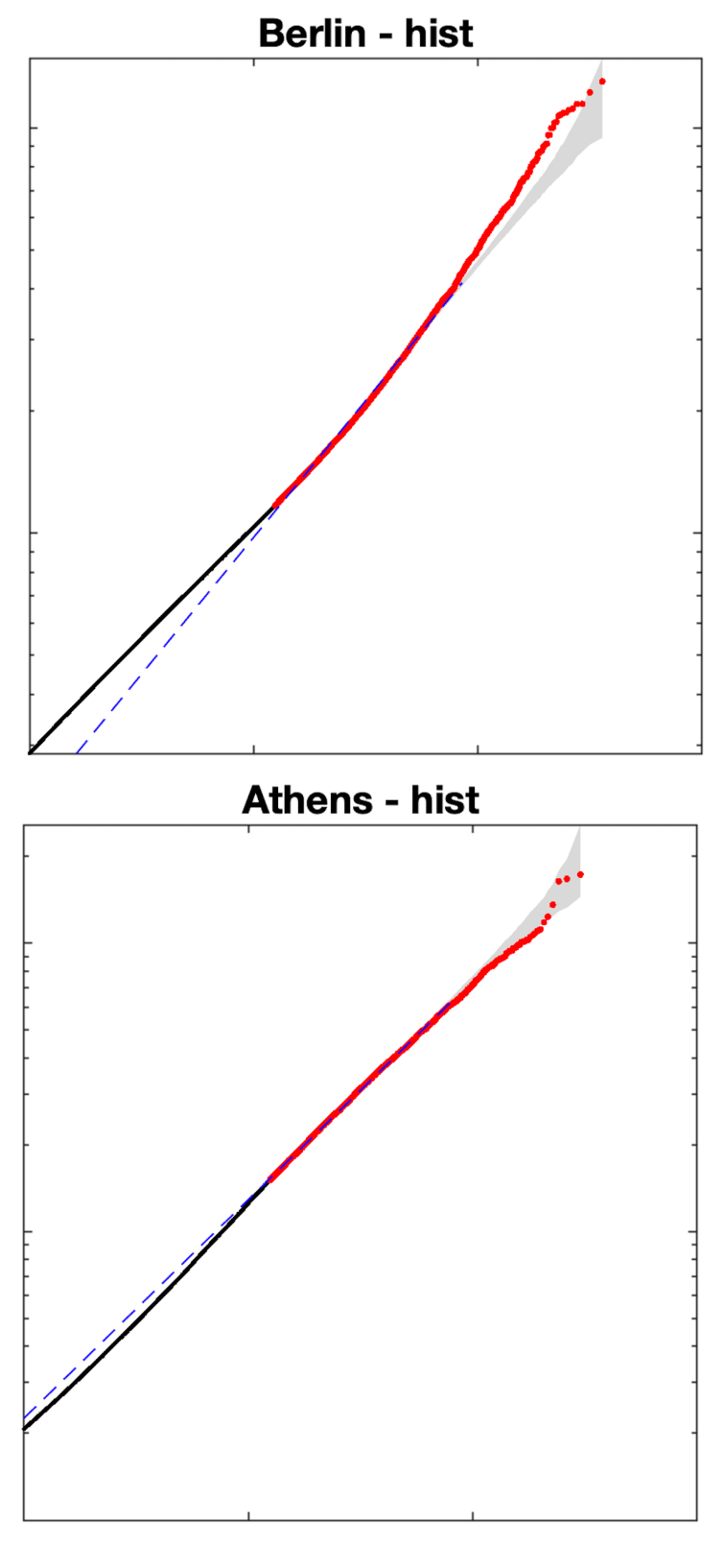
Physical basis and importance of the temperature model







Same magnitude model (Weibull)
Different tail behavior

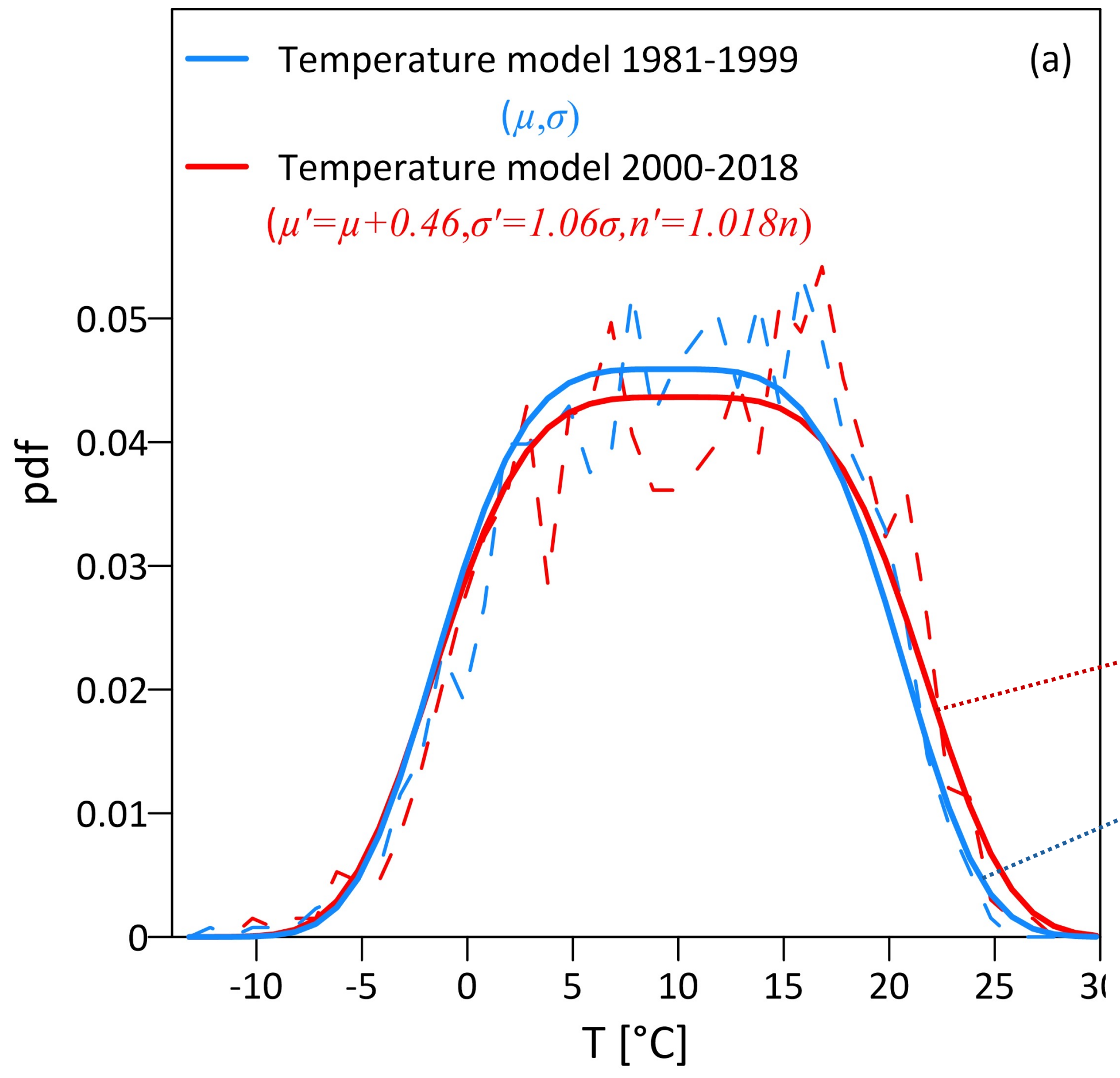


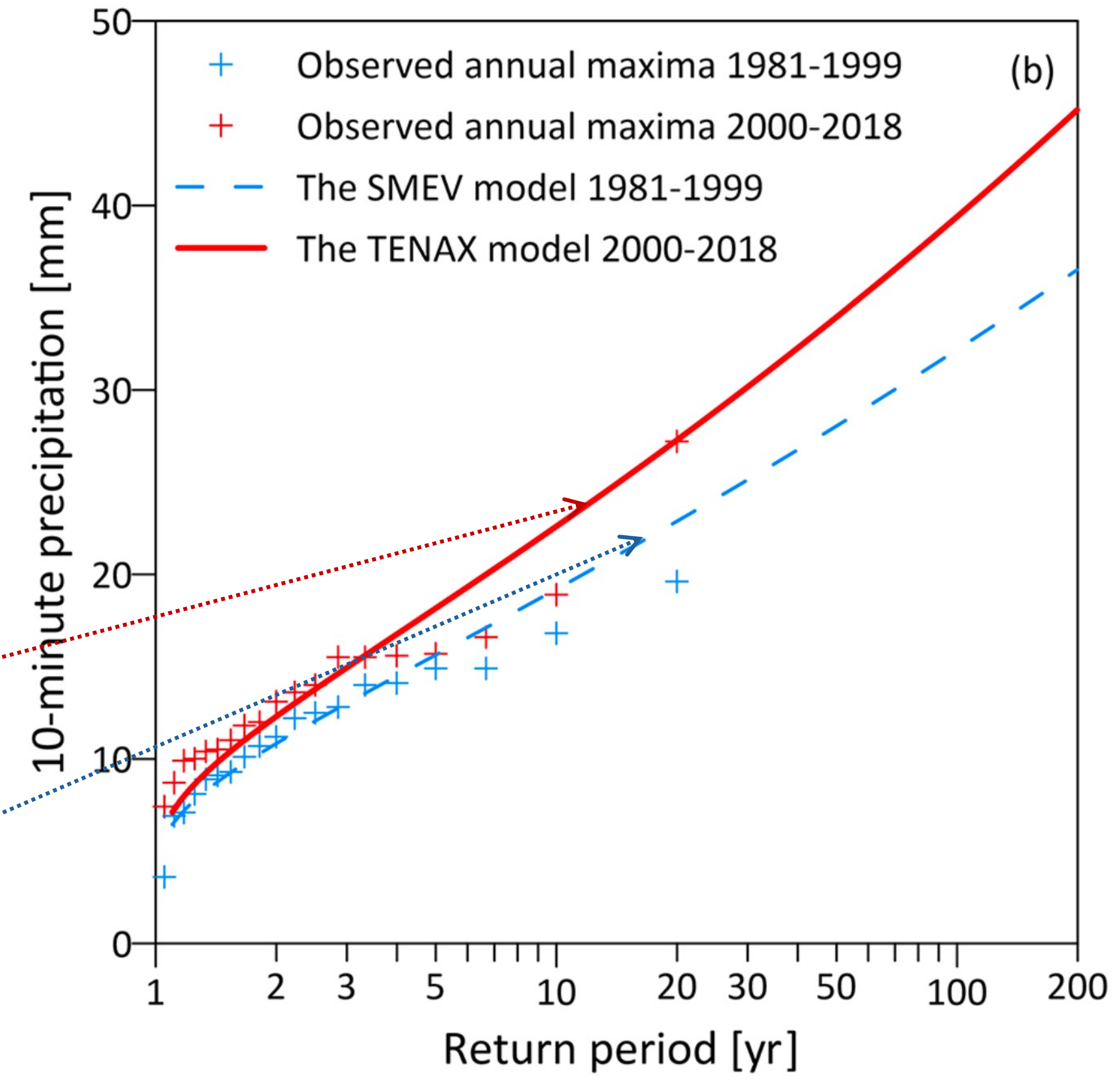
Predicting future return levels based on changes in daily temperature

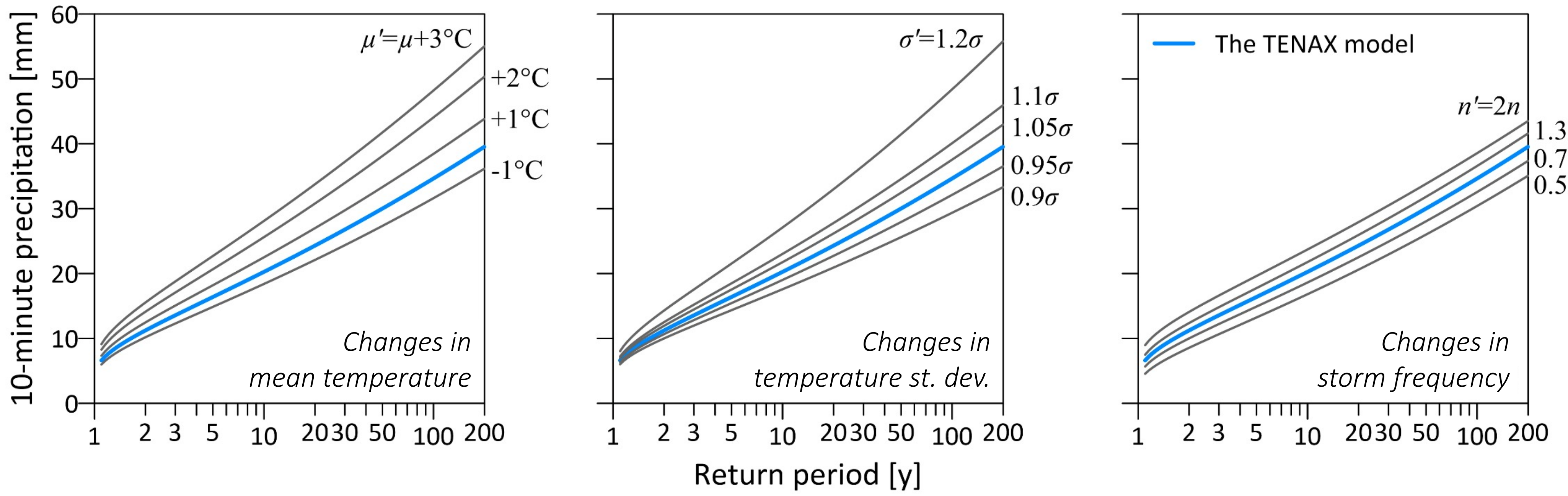
Hindcast validation:

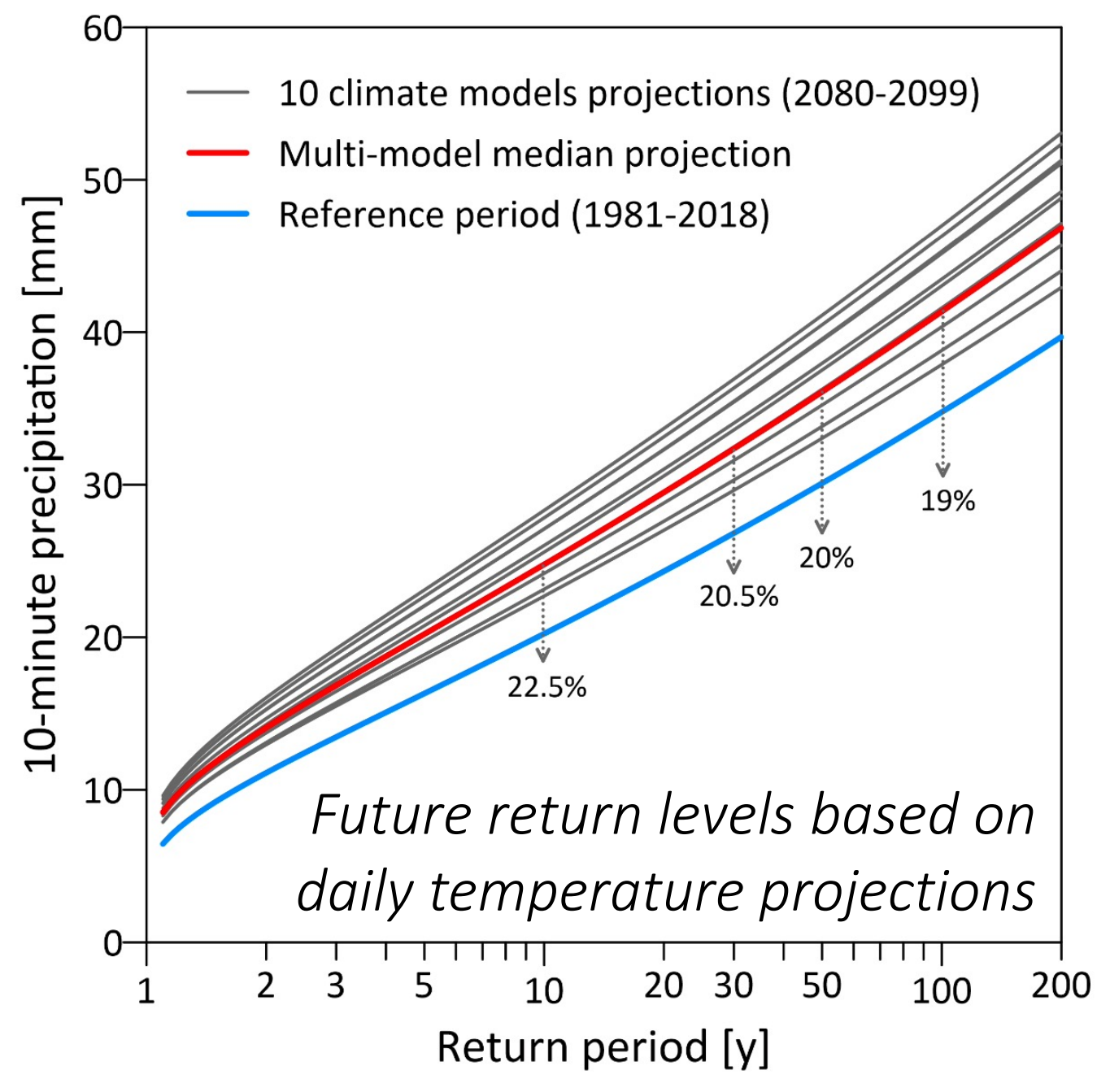
1. Split data into two time slices (equal length) (1981-1999, 2000-2018)
2. Estimate *W* from 1981-1999 only (contains information on the physics)
3. Estimate changes in mean and variance of *g* from 1981-1999 to 2000-2018
4. Predict return levels for 2000-2018 using *W* estimated from 1981-1999 and projected changes in *g*

- Sensitivity to changes in mean, variance and storm occurrence frequency
- Future projections based on changes in temperature in an ensemble of 10 regional climate models









This study was funded by
- Department of Geosciences, University of Padova (TENAX project) as part of The Geosciences for Sustainable Development project (CUP C93C23002690001)
- SNSF (grant no. 194649, Rainfall and floods in future cities)
- CARIPARO (Excellence Grant 2021, Resilience project)

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

Codes are freely available:
https://doi.org/10.5281/zenodo.8345905

Paper

Codes

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