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Supplement of

Estimation of future rainfall extreme values by temperature-dependent disaggregation of climate model data

Niklas Ebers et al.

Correspondence to: Hannes Müller-Thomy (h.mueller-thomy@tu-braunschweig.de)

This supplementary consists of two sections. In the first section, we validated the stationarity of the scaling behaviour and our general temperature-dependent disaggregation approach using an observed rainfall time series at the station Bochum (Germany). In the second section, we compared the disaggregation results regarding rainfall extreme values with a convection-permitting climate model.

1. Section: Scaling behaviour and temperature-dependent disaggregation station Bochum

In this supplementary material we present a proof-of-concept for the temperature-dependent cascade model. Two periods from an observed time series with different annual mean temperatures are selected and then used for cascade model parameter estimation as in the main manuscript. Changes of the rainfall extreme values can then be analysed between both periods.

For this proof-of-concept the station Bochum (N51.5026 °, E7.2289 °) with a time series length of 45 years was chosen (measuring periods: 1940-1959, 1979-1993 and 2008-2017). This time series is not part of the data set used in the main manuscript, but was selected due to its time series length. Based on the annual temperature the time series was split in two time series, one with colder years and the other one with warmer years. The threshold to classify in cold and warm years was an annual mean temperature of 10.5 °C. The resulting times series have a length of 21 years for $\text{condition}_{\text{cold}}$ and 24 years for $\text{condition}_{\text{warm}}$ (Fig. S1). The mean temperature difference between the two time series is 1.2 K. This temperature difference is comparable to the temperature increase (approximately 1.2 K) from C20 (1971-200) to the NTF (2021-2050) that is projected by the climate scenario data based on RCP 4.5 across all locations in our study.

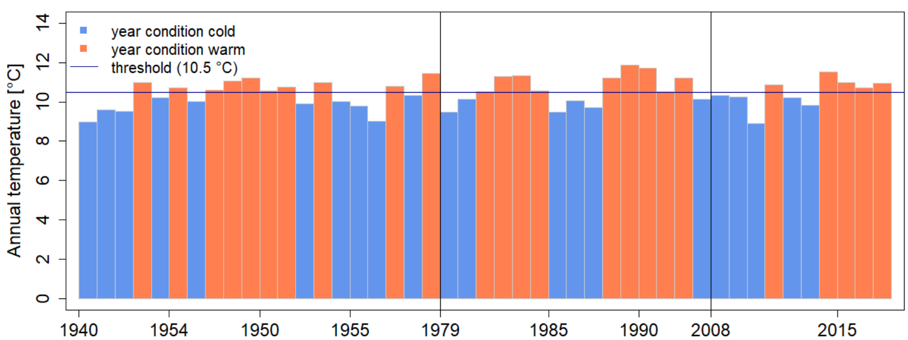

Figure S1: Composition of the period with cold years ($\text{condition}_{\text{cold}}$) and the period with warm years ($\text{condition}_{\text{warm}}$) based on the annual temperature at the station Bochum (available periods: 1940-1959, 1979-1993, 2008-2017).

To validate our key assumption regarding the scaling behaviour, we have analysed the first three moments of both periods (Fig. S2). The scaling behaviour is linear for temporal resolutions larger than 50mins and for temporal resolutions lower than 50mins, which underlines the possibility of a partly scale-invariant parameter estimation (parameter reduction approach S1). All three moments show a similar scaling behaviour in both time series. For coarser temporal resolutions, the scaling difference increases. However, the difference is relatively small (<5%). This analysis serves as evidence supporting our assumption of parameter transferability among colder and warmer periods when temperature-dependency is taken into account.

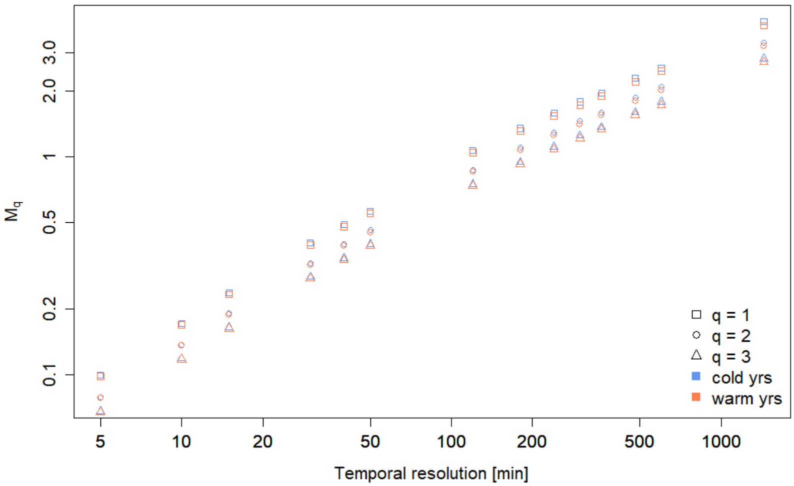

Figure S2: Probability-weighted moments of rainfall time series for the years with condition$_{cold}$ and condition$_{warm}$ for station Bochum.

To validate our general approach, we analysed the change in rainfall extreme values with a return period of T2= 2yrs and T5= 5yrs for the duration D= 5min between the condtion$_{cold}$ and condition$_{warm}$ time series (Tab. S1). For the observed data a difference of 6% for T2 and 9% for T5 can be found, resulting in an increase of the rainfall extreme values.

For the disaggregation model, we estimated the model parameters using the condtion$_{cold}$ time series and disaggregated both time series. For this a disaggregation model without temperature dependency (S1-P1 in our study) and a disaggregation model with temperature dependency (S1-P1-TD in our study) was used. The disaggregation model without temperature dependence shows a slight decrease in the rainfall extreme values for both return periods (T2= -4% and T5= -5%). Although an increase in temperature can be observed, this model shows no increase in rainfall extreme values comparable to the observed values. In contrast, the model with temperature dependence shows an increase for both return periods (T2= +3% and T5= +6%). However, this increase is slightly smaller than the observed changes.

This proof-of-concept shows that the temperature dependent disaggregation model can reproduce an increase in rainfall extreme values induced by an increase in temperature. An application for climate scenario data affected by a temperature increase to analyse future changes in rainfall extreme values is therefore permissible.

Table S1: Relative change between the condition$_{cold}$ and condition$_{warm}$ time series for the observation and disaggregation results of the disaggregation model without temperature-dependency (S1-P1) and with temperature-dependency (S1-P1-TD).

Dataset	Relative change condition$_{cold}$ to condition$_{warm}$ time series [%]	
	Return-period	
	2yr	5yr
Observed	+ 6	+ 9
S1-P1	- 4	- 5
S1-P1-TD	+ 3	+ 6

2. Section: Comparison with a convection-permitting climate model

The DWD provides results of a single convection-permitting climate model (CPM), which will be considered as ‘future truth’ due to its physical-close modelling of the atmosphere (CPM data; https://esgf.dwd.de/projects/dwd-cps/cps-scen-v2022-01). With CPM, the absolute rainfall extreme values obtained from the disaggregated DWD core ensemble (CE) are validated. This analysis is limited to the long-term future (LTF), as it is the only period which is covered by both climate model data sets, and to hourly values (finest resolution of CPM). CPM has an hourly temporal resolution and was space spatially aggregated (from 3 km to 5 km) to enable a comparison with the CE results. The rainfall extreme values with return periods of T=2 yrs and T=10 yrs for a duration of D=1 h between the CE and CPM are shown in Fig. S3. It can be seen, that the extreme rainfall values obtained from the CPM fall within the range of those from the CE for all stations, in most cases between the lower and upper quartile of the CE results. The CE extreme values envelop the CMP extreme values proving the plausibility of our results.

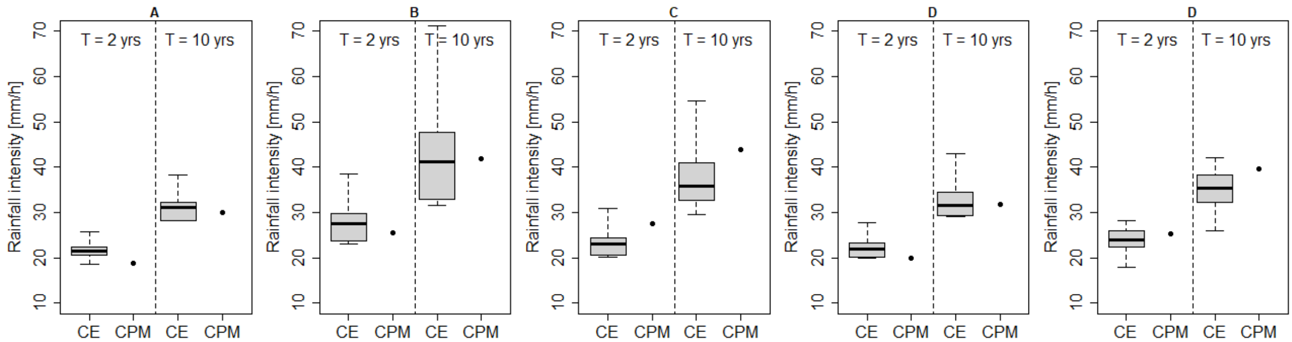

Figure S3: Comparison of rainfall extreme values with return periods T=2 yrs and T=10 yrs for D=1 h for the disaggregated DWD core-ensemble (CE) and the convection-permitting climate model (CPM) for the station subset A-E in the long-term future (2071-2100).