Assessing the occurrence of compound hot and dry events from pre-industrial conditions to present-day extremes

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1. INTRODUCTION

Heatwaves and dry spells are major climate hazards that severely impact human health, economy, agriculture, and natural ecosystems. **Compound hot and dry summers** have become more frequent and intense in recent years in Europe: **2003, 2015, 2018, and 2022** (Rousi, Efi, et al., 2022). What remains unclear is, however, to which extent the observed trend can be explained by climate change or as a feature of internal climate variability. In this study, we assess the frequency and intensity of compound hot and dry events in Europe by analyzing recent historical events and comparing it to data derived from a **50-member Single Model Initial-condition Large Ensemble (SMILE)** for the following four periods:

- **PI** pre-industrial climate conditions without climate change
- **PRESENT** 2001-2020 +1.2 K : present conditions
- **GWL+2K** 2021-2040 +2 K : Paris Agreement; positive perspective
- **GWL+3K** 2042-2061 +3 K : realistical perspective following current trend

Research question:

What is the probability of historical events like 2003, 2015, 2018, and 2022 to happen without CC? What is the probability of the events happening given CC?

2. DOMAIN AND DATA

ERA5

- June-July-August (JJA) seasonal average temperature (tas) precipitation (pr)
- 2000-2022

Pre-industrial control run of CRCM5-LE

- JJA seasonal average tas & pr
- 700 years (20 years * 35 members)

CRCM5-LE European domain, driven by CanESM2

- JJA seasonal average tas & pr
- Canadian Regional Climate Model 50 member Single Model Initial-condition Large Ensemble (CRCM5-LE) driven by Canadian Earth System Model (CanESM2)
- 1000 model years for PRESENT, GWL+2K and GWL+3K each (20 years * 50 members)

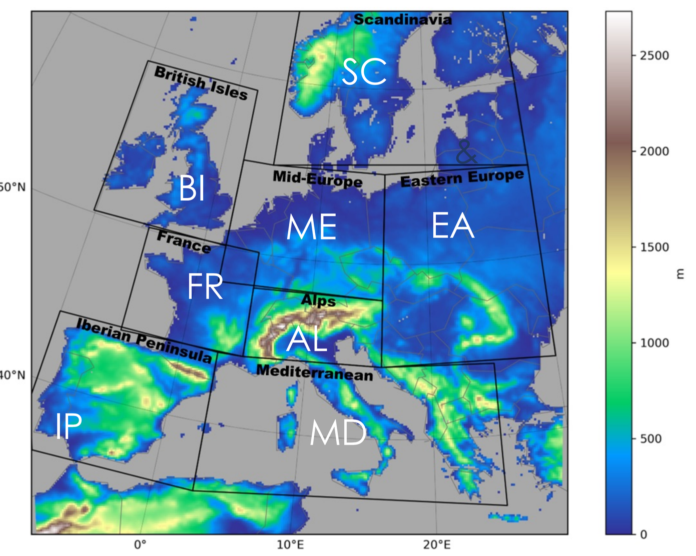

Fig. 1 The orography [m] over the European domain of the CRCM5-LE in 0.11° resolution and the sub-regions used in the analysis adapted from **Böhnisch A, Mittermeier M et al. (2021).**

Africa excluded; sea grid cells excluded in all datasets

3. METHODS

- Detrending tas for every period for every GWL in CRCM5 and ERA5
- Performing **quantile mapping bias correction** (BC) for temperature and precipitation under the assumption that CRCM5-LE 2001-2020 & ERA5 2001-2020 represent the same climatology

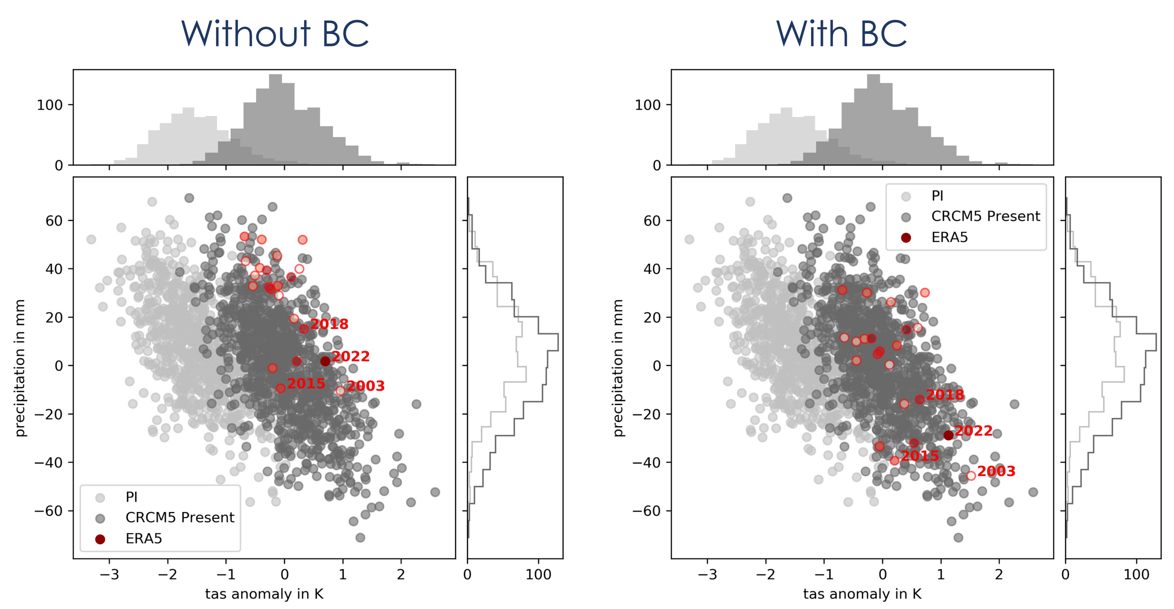

Fig. 2 Scatter plot for anomalies in tas [K] and pr [mm] for PI, CRCM5 Present and ERA5 without bias correction (left) and with (right) averaged over the whole European domain.

4. RESULTS FOR EUROPE

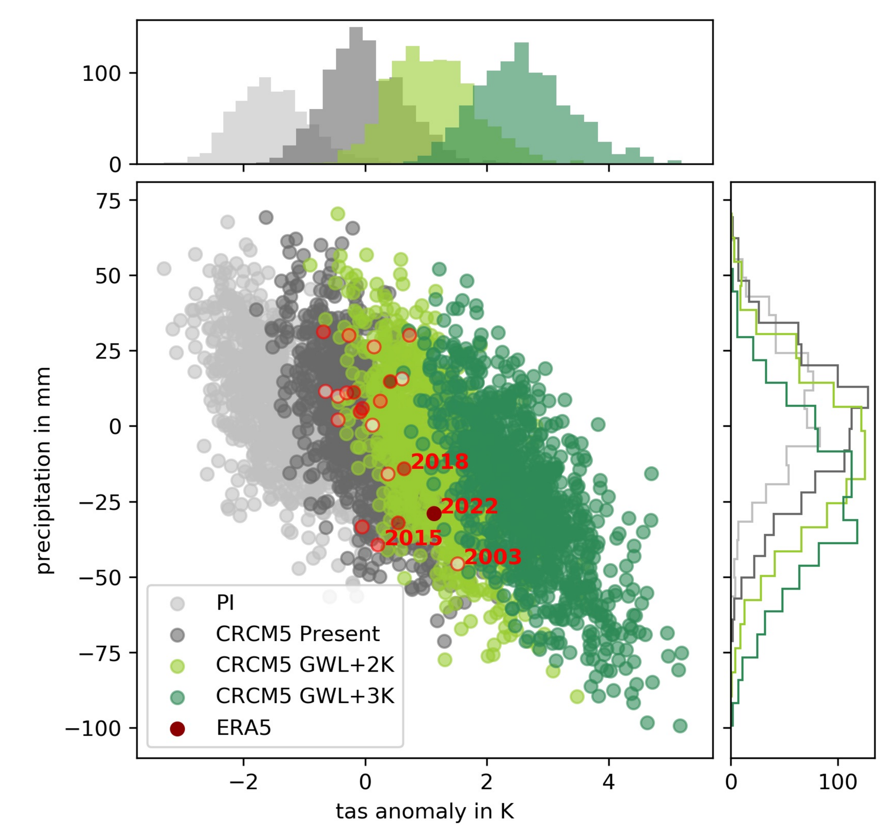

Fig. 4 same as Fig. 2 right but for all time periods

- **2003 event among the most extreme** events on the European scale
- Under GWL+2K and GWL+3K those events will become a **common feature of European climate**
- There is a considerable shift toward **more drier and hotter events with every GWL**
- The change is driven by **changes in both temperature and precipitation**, although more dominated by temperature

5. RESULTS PER EVENT

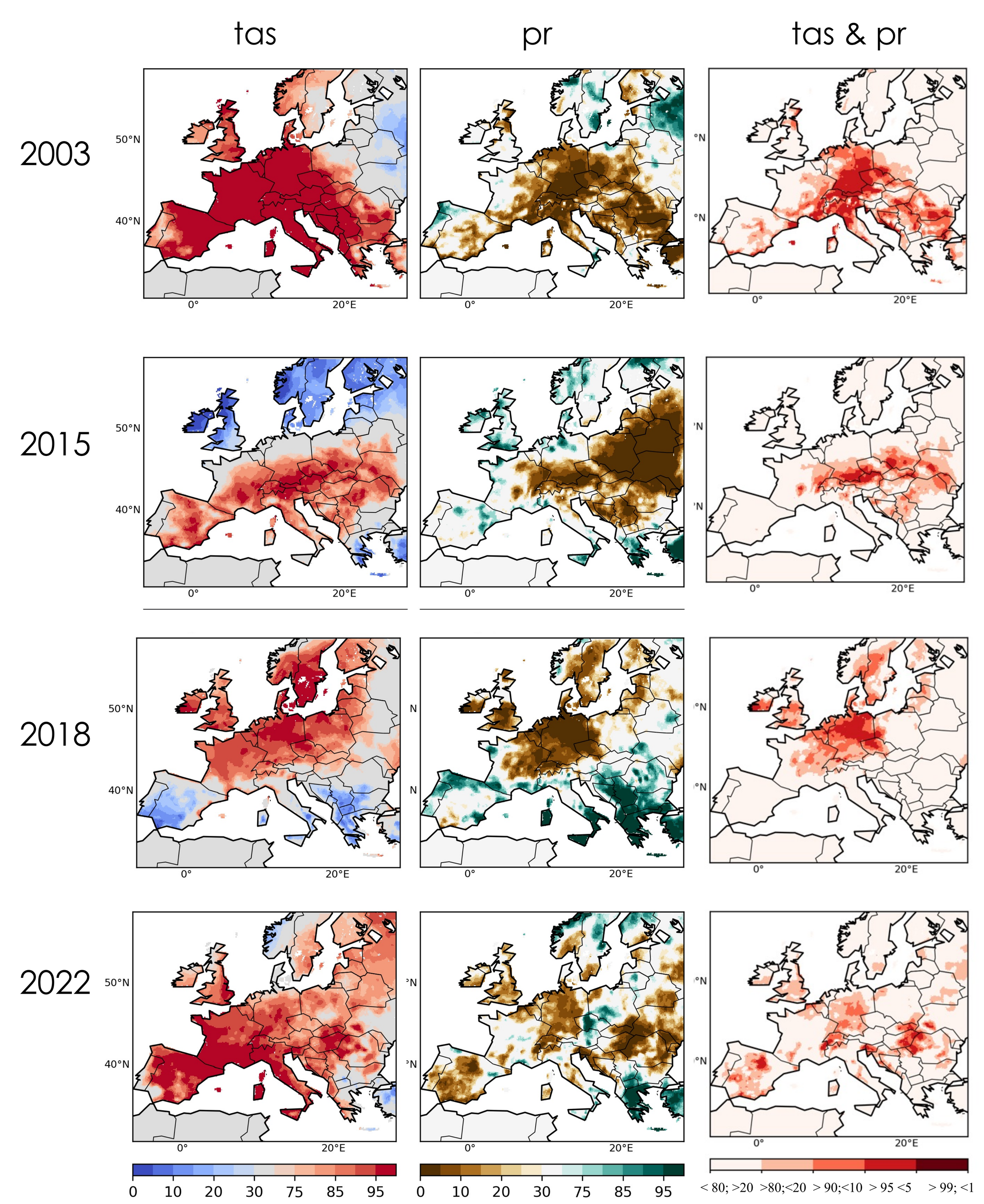

Fig. 3 tas percentile (left column), pr percentile (middle column) and combined percentile thresholds of tas & pr (right column) for four chosen historical events (rows) in reference to ERA5 2001-2020

Tab.1 Event probability in **%** in regions that were experiencing the event for the four chosen periods. The probability corresponds to a probability of **a summer as hot and dry or hotter and drier than the historical event**

Bold: return period >= 10 years

region	PI	PNT	GWL+2K	GWL+3K
BI	0,1	5,7	**19,9**	**44,7**
IP	0,0	0,4	8,3	**54,6**
FR	0,0	0,1	3,6	**24,5**
ME	0,0	0,2	1,5	6,0
AL	0,0	0,0	0,8	7,6
MD	0,0	0,5	8,4	**30,2**

region	PI	PNT	GWL+2K	GWL+3K
AL	0,3	3,2	**13,3**	**30,3**
EA	0,1	0,6	1,4	1,1

region	PI	PNT	GWL+2K	GWL+3K
ME	0,0	0,5	1,7	3,9
SC	0,9	4,9	9,1	**11,6**
BI	0,0	3,3	**11,8**	**20,8**

region	PI	PNT	GWL+2K	GWL+3K
IP	0	2,8	**17,7**	**55,4**
FR	0,1	3,2	**17,9**	**56,4**
AL	0,1	2,3	**16,9**	**39,7**
ME	1,3	9,3	**19,4**	**32,9**

- The probabilities for all the events rise from **0-1% in the preindustrial conditions** to up to **10% in the present climate**
- All of the chosen events are **enabled by climate change** – the probability of occurrence in the pre-industrial climate conditions is zero for at least one region for every event
- All of those events will have a return period of **10 years or less under GWL +2K in some regions**
- GWL+2K is a more favorable scenario with **occurrence probabilities 2-3 times smaller** when **compared to GWL+3K**

6. RESULTS PER REGION

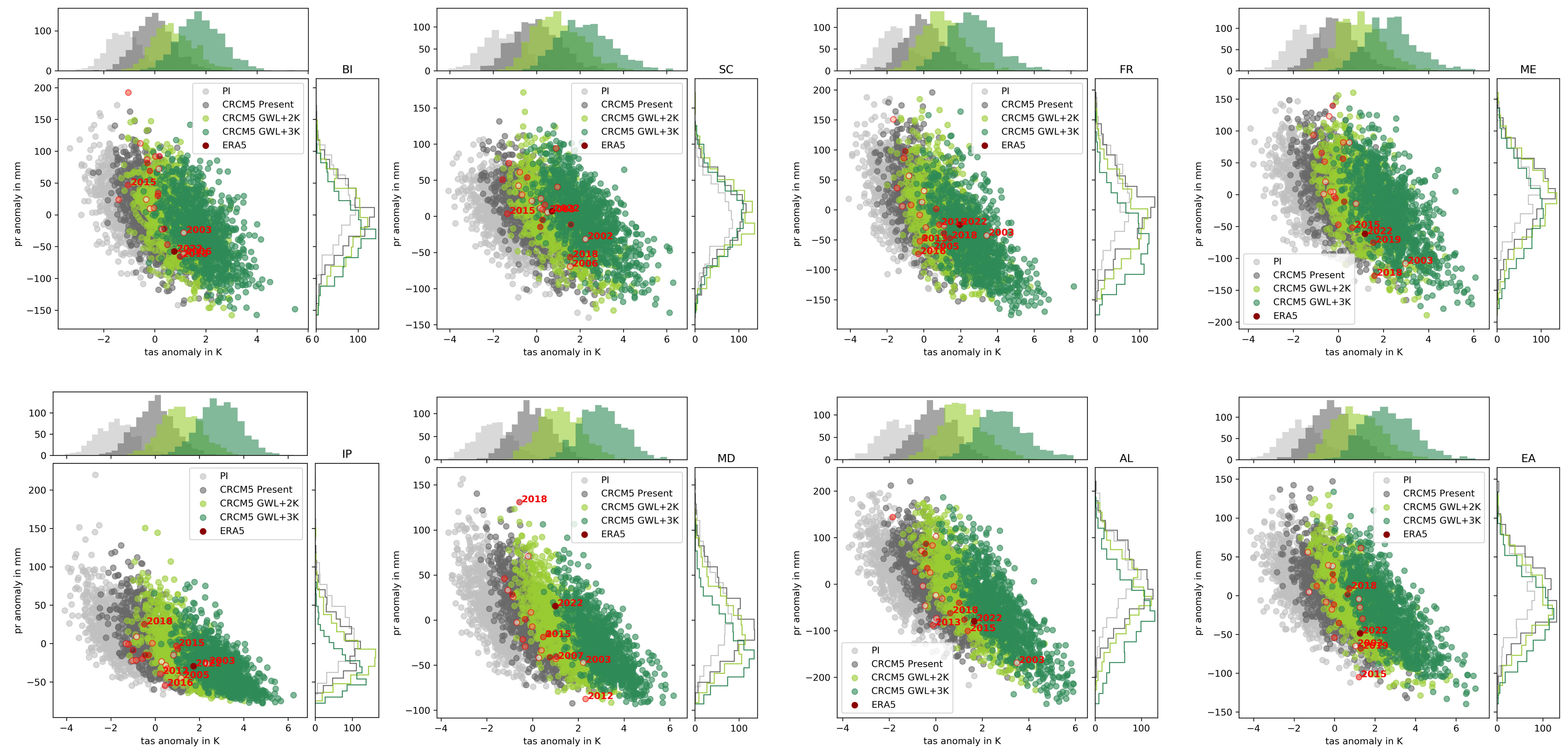

Fig. 5 same as Fig. 4 but averaged over the chosen sub-regions ordered from North to South from West to East

- There is a shift in **all distributions towards more hot values**, some become more heavy-tailed as e.g. FR and MD domain
- The **climate becomes drier** in all but one case of SC
- Besides the events of 2003, 2015, 2018 and 2022 events in **2006, 2008,2012, 2013, 2016, 2019** were among the most extremes in different regions

7. CHALLENGES AND NEXT STEPS

- Currently univariate quantile mapping bias correction, will be adjusted to **bivariate bias correction**
- Currently simple AND definition of the event; future aim to adapt a **Survival Kendall definition** of threshold
- Apply **GEV** to precisely estimate **return periods** for the historical events given the future climate
- Further investigation of hotspots and impacts of compound hot and dry events in **Böhnisch et. al. (2023)**

8. TAKE HOME MESSSAGE

- Limiting global warming to **+2K** would **significantly reduce** occurrence probabilities of extreme hot and dry events **up to three times**
- Under a global warming of +3K, **events like the 2003** heatwave and dry spell may become a **common feature** of the European climate due to heating and drying effects.
- **SMILEs** are essential for **event attribution** and enable the assessment of historical compound events by offering a **robust statistical basis for estimating the probability** and return period of extreme events.

Literature: Rousi, Efi, et al. (2022): "The extremely hot and dry 2018 summer in central and northern Europe from a multi-faceted weather and climate perspective." EGUsphere (2022): 1-37; **Böhnisch A, Mittermeier M et al. (2021)** Hot Spots and Climate Trends of Meteorological Droughts in Europe–Assessing the Percent of Normal Index in a Single-Model Initial-Condition Large Ensemble. Front. Water 3:716621, **Böhnisch, A.**, Felsche, E., Mittermeier, M., Poschlod, B., and Ludwig, R.: Hotspots and impacts of present and future compound hot and dry summers in Europe, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-2079, https://doi.org/10.5194/egusphere-egu23-2079, 2023; **Cannon, A. J.**, Sobie, S. R., & Murdock, T. Q. (2015). Bias correction of GCM precipitation by quantile mapping: how well do methods preserve changes in quantiles and extremes?. Journal of Climate, 28(17), 6938-6959.

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