

created with AI

NUKLEUS – A first kilometer-scale multi-model ensemble for Germany

Latest Insights and Applications

Florian Ehmele, Christoph Braun, Christian Beier, Hendrik Feldmann, Kevin Sieck, Joaquim Pinto, et al.

Gefördert durch:

Bundesministerium für Forschung, Technologie und Raumfahrt

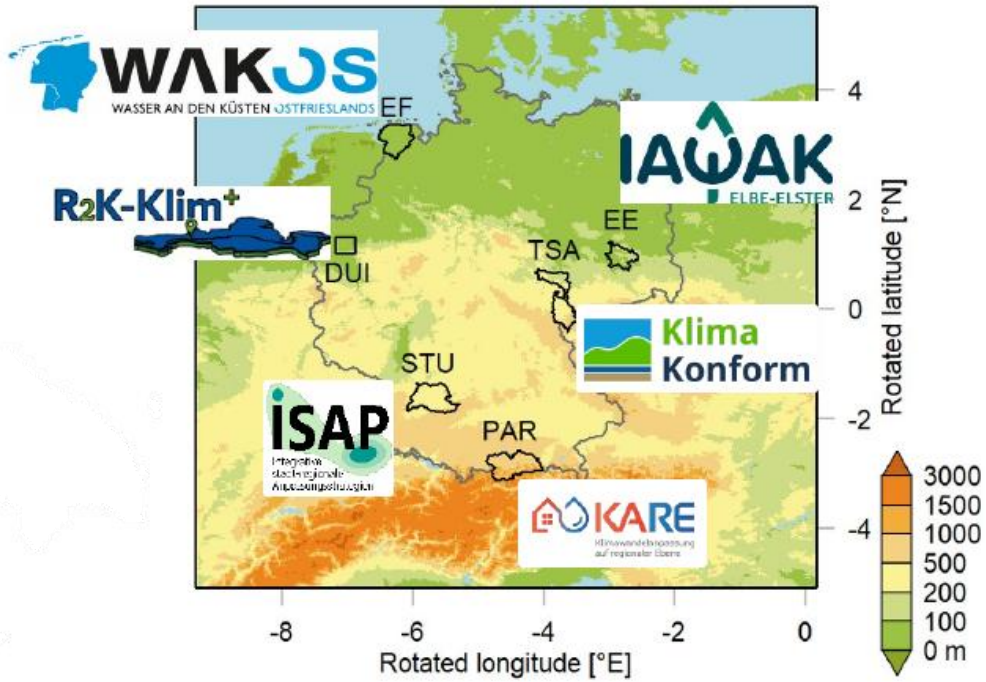
FONA Forschung für Nachhaltigkeit

Regional Information for Action on Climate Change

Goal and structure:

- Interdisciplinary funding measure to transfer climate information to local climate action
- 6 Model Regions: Develop and implement tools for decision support for regional adaptation to climate change
- Cross-cutting activity **NUKLEUS**: **Provision of climate data**
- Cross-cutting activity WIRKsam: Climate adaptation research, scientific coordination and outreach

The overarching goal is to develop a web-based climate information platform that supports specifically climate adaptation action – the "**KlimaFolgenHub**"



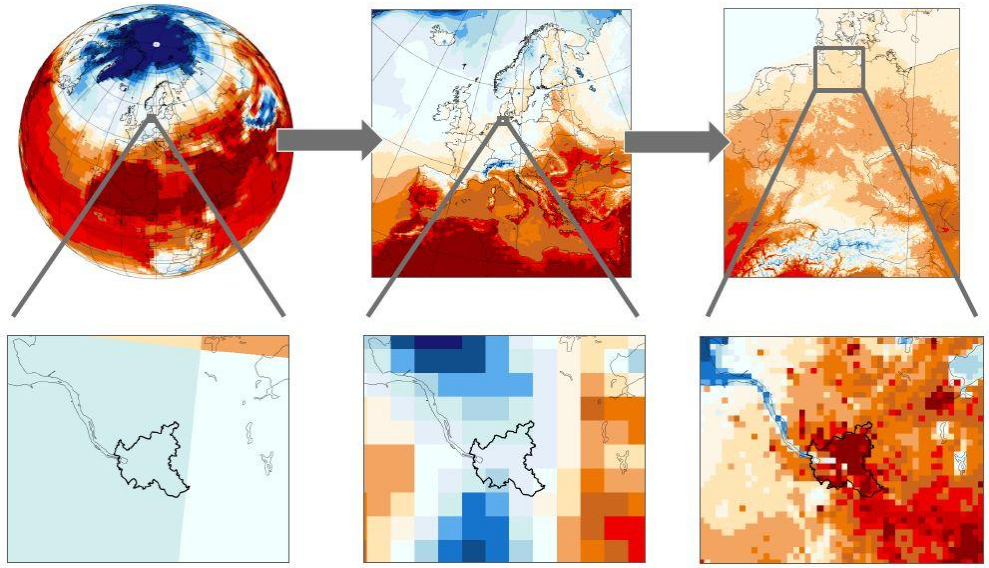
The NUKLEUS Ensemble

Nutzbare lokale Klimainformationen für Deutschland

Simulation protocol and strategy:

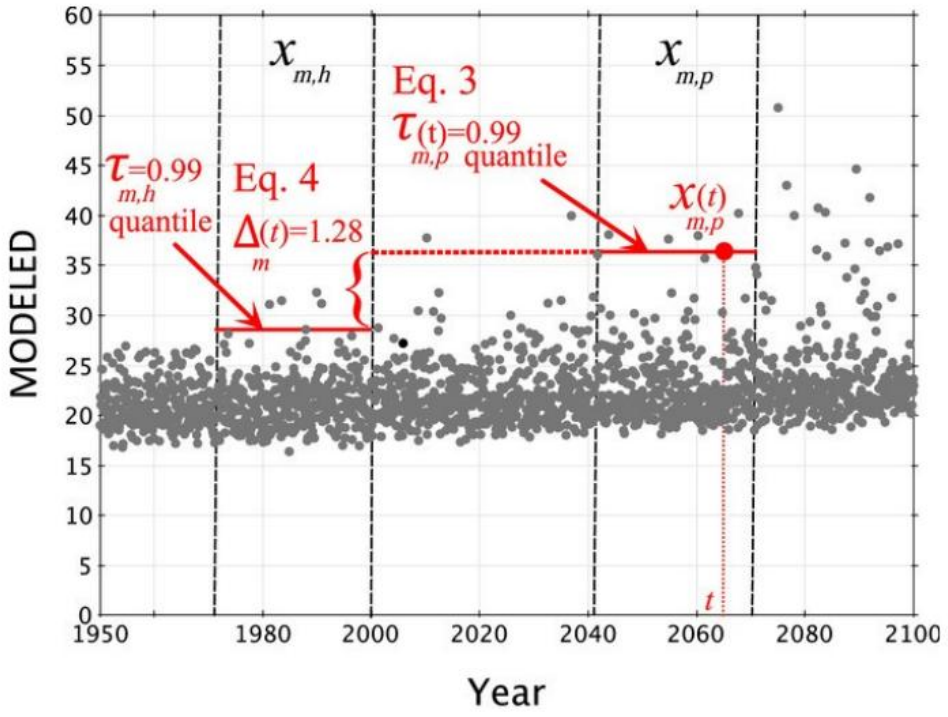
- **3 CMIP6 GCM** downscaled by **3 RCM**
  - **GCM / Reanalysis** → **RCM** at 12km EURO-CORDEX (EUR11) → **CPM** at 3km Central Europe (CEU3)
  - ssp3-7.0
- Transient at 12km
  - Evaluation: **ERA5-driven** (1979 – 2020), *3 member*
  - Scenarios: **GCM-driven** (1950 – 2100), *9 member*
- Time-slices at 3km
  - **Evaluation** (2005 – 2014)
  - **Historical** (1961 – 1990) corresponding to a global warming level of +0.42K vs. preindustrial
  - **Future** for global warming level +2K (GWL2K) vs. preindustrial
  - **Future** for global warming level +3K (GWL3K) vs. preindustrial

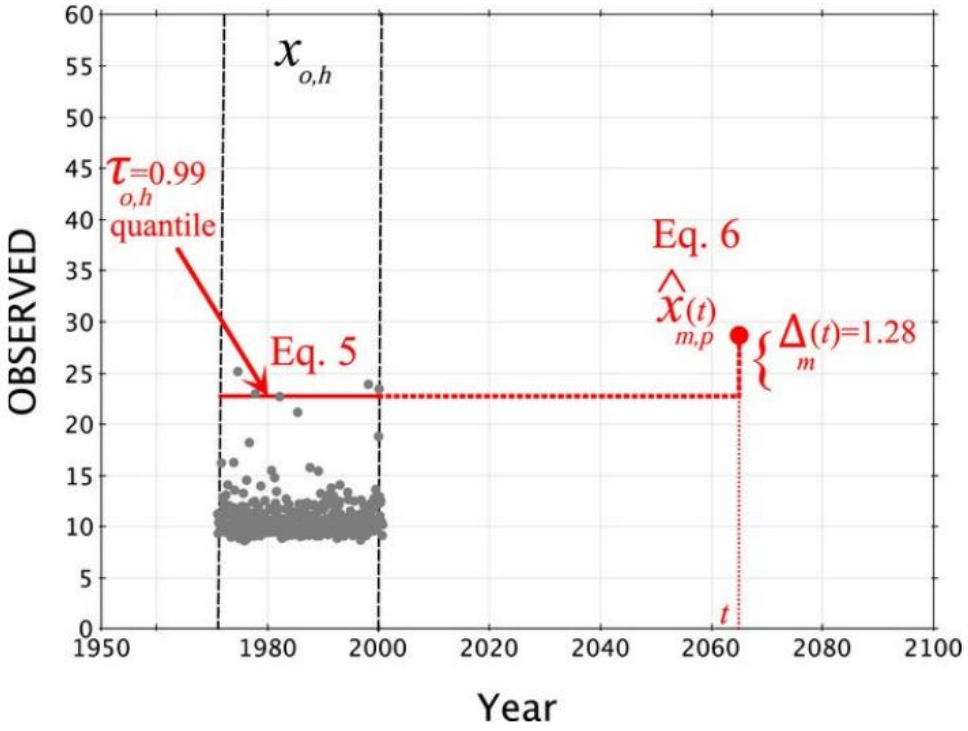
	ICON-CLM	CCLM	REMO
ERA5	x	x	x
MPI-ESM	x	x	x
EC-Earth	x	x	x
MIROC6	x	x	x



Bias correction

- **Quantile Delta Mapping** (QDM)
  - Reference: HYRAS-DE
  - Daily Tmean, Tmin, Tmax, precip
- Adjusting the **statistical distribution**
  - Independently for each grid point
  - Independently for each variable
  - Monthly differentiated
- **Climate change signals**
  - Preserved for individual models





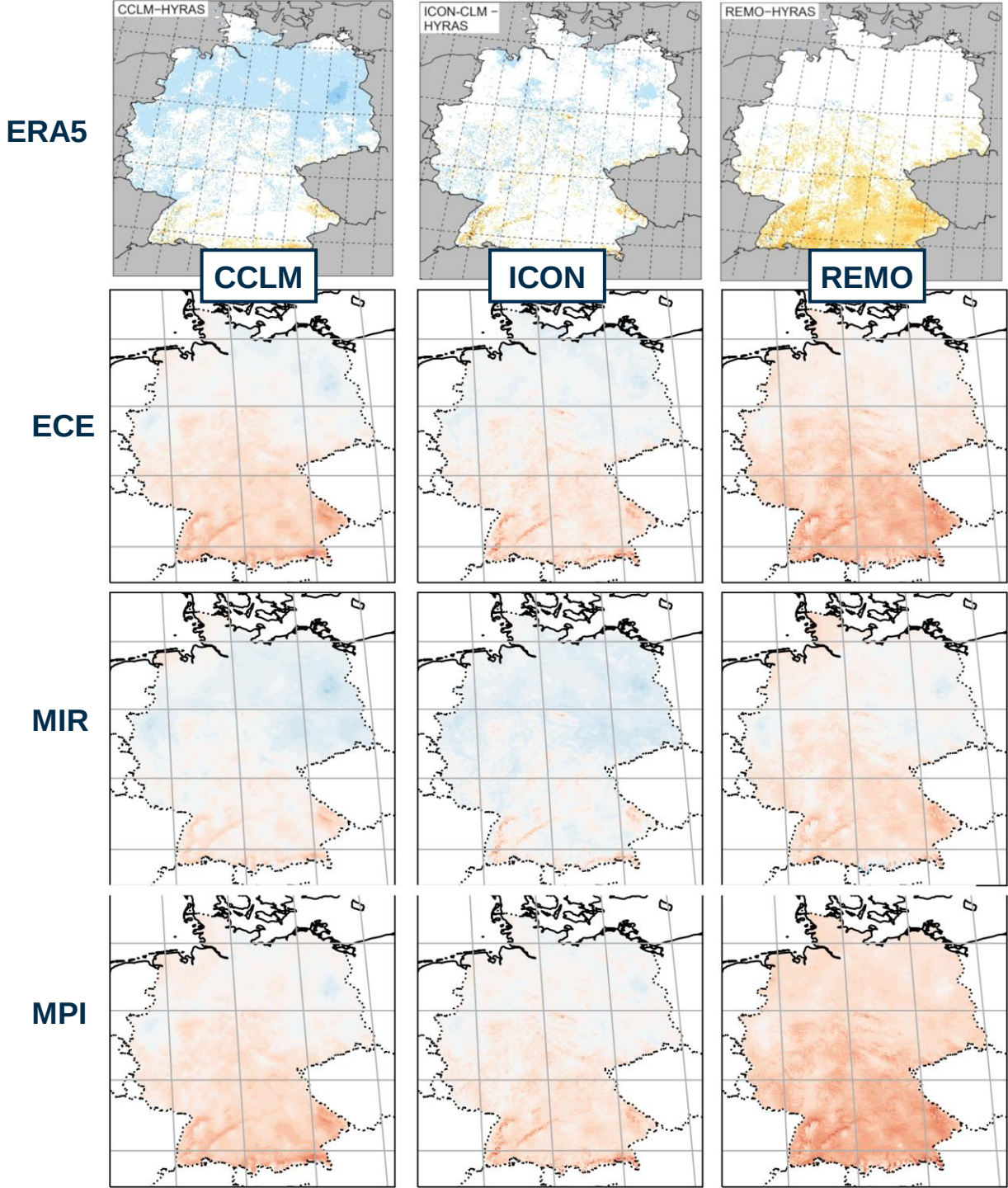
Cannon et al. (2015)

Evaluation runs & Historical simulations

Temperature:

- Spatial bias pattern dominated by used RCM
- Magnitude of bias dominated by driving GCM
- Warm bias more pronounced in mountainous areas
- MIROC-driven simulation with cold bias in winter
- REMO shows “hot spots” (strong warm bias) corresponding to the big cities, especially in daily maximum summer temperature

Figure: Mean bias of annual temperature



Publications:

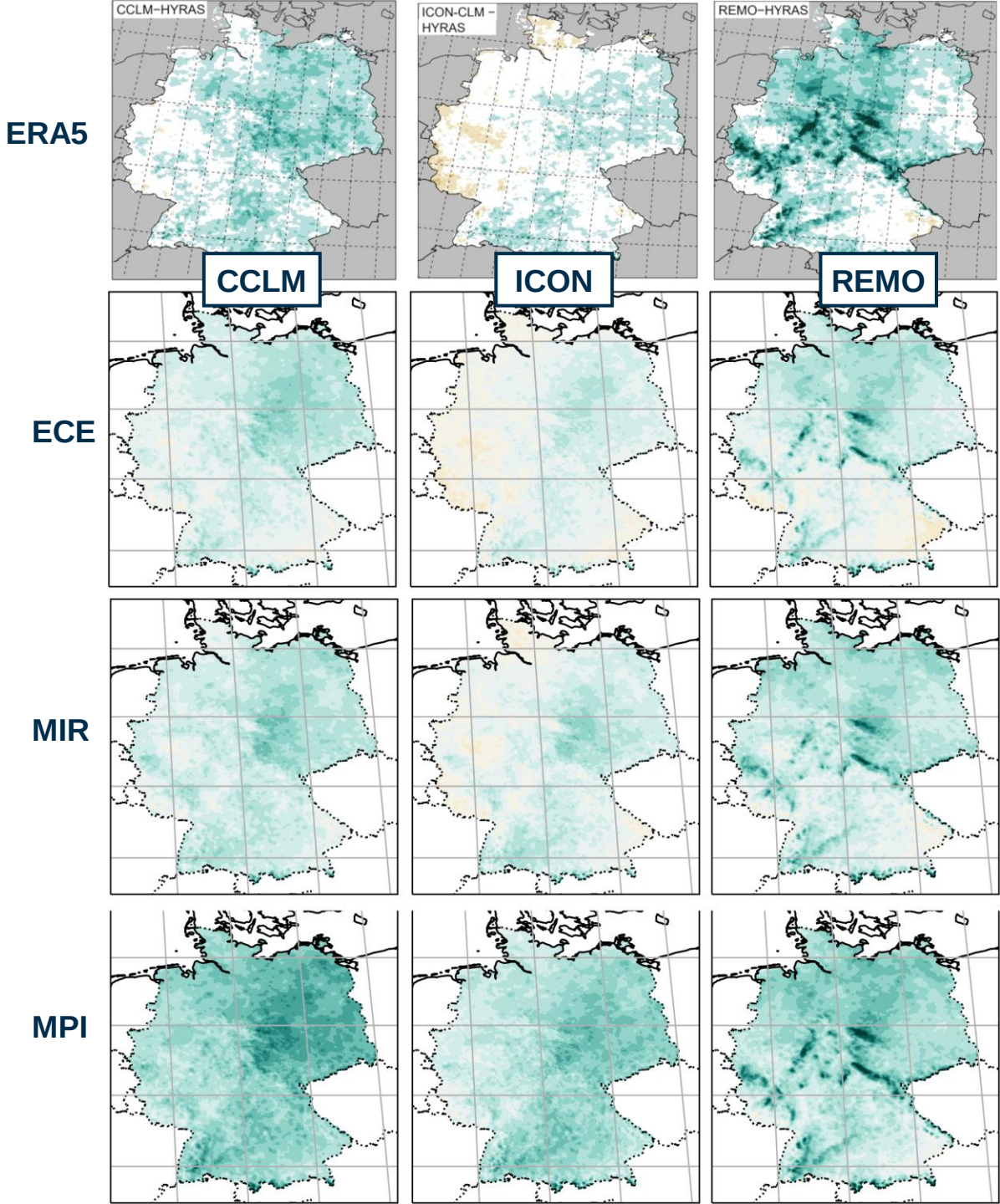
- Sieck et al. (Preprint): GMD, https://doi.org/10.5194/egusphere-2026-1024
- Braun et al. (Preprint): GMD, https://doi.org/10.5194/egusphere-2026-2517

Evaluation runs & Historical simulations

Precipitation:

- Spatial bias pattern dominated by used RCM
- Wet biases mainly from winter precipitation
- Mainly small wet or dry biases in summer
- REMO with stronger orographic signals
- MIR-driven runs tend to show the highest intensities

Figure: Mean bias of annual precipitation

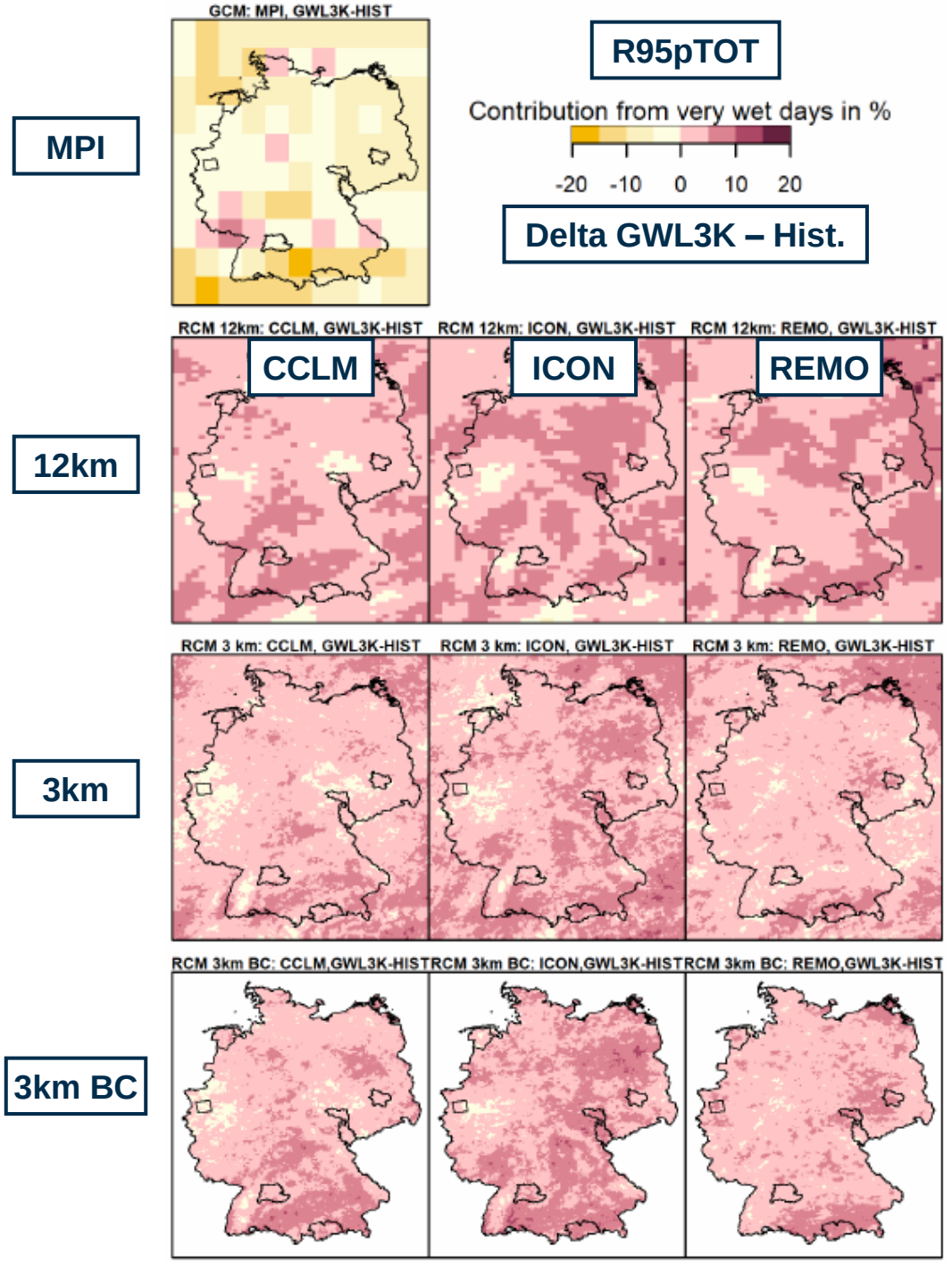


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Future scenarios

- Overall increase **in temperature and T-extremes** (more pronounced during nighttime)
- Smaller trends for **seasonal precipitation** (increase in winter, decrease in summer)
  - annual totals roughly unchanged, but higher and more frequent extremes
- T-based indices with **higher robustness** than Pr-based indices in 3km vs. 12km vs. GCM
  - Better representation of local features, but stronger noise
- **Small effect of QDM** on T-based indices, but more for Pr-based indices
  - spatial pattern unchanged after QDM

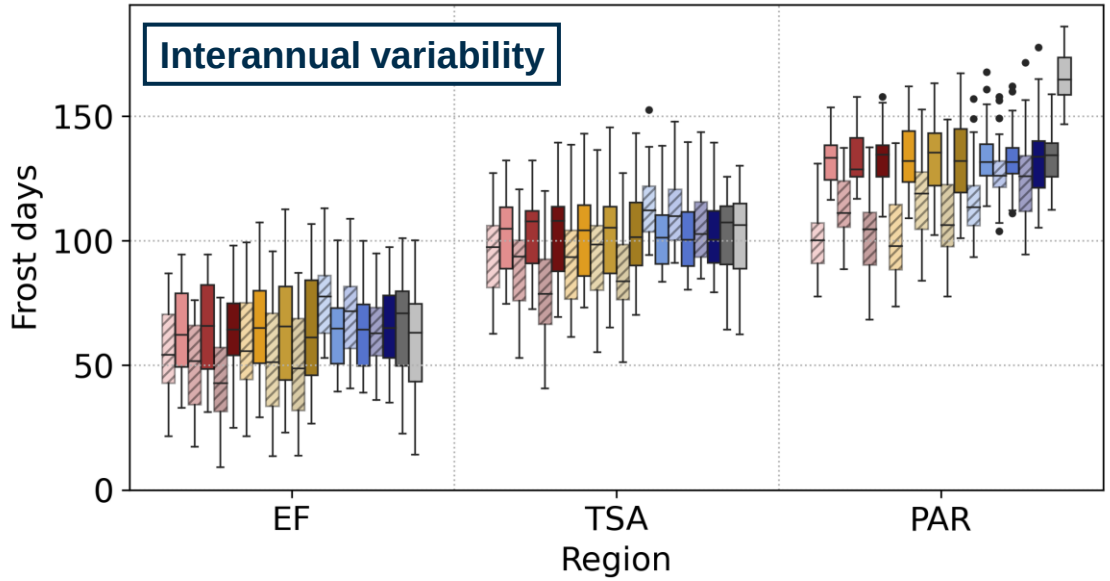


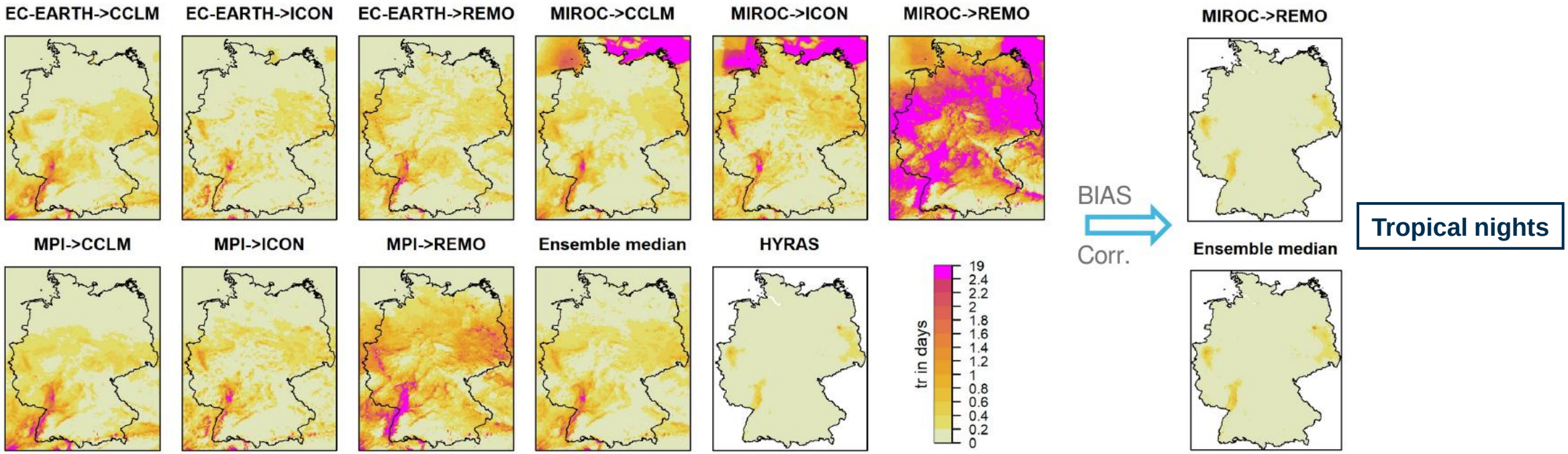
Publication:

Beier et al. (accepted for publication): J. Climate, https://doi.org/10.1175/JCLI-D-25-0613.1

Bias correction – Pro's

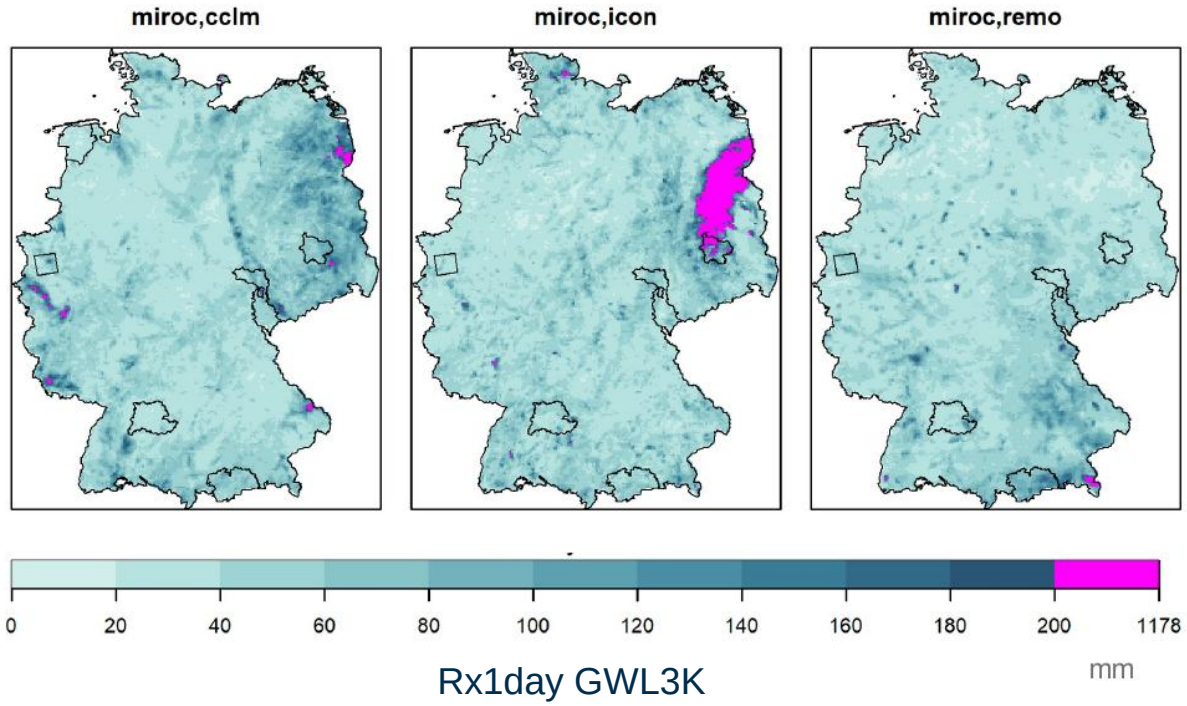
- QDM successfully removes climatological (**mean**) biases
- Mean statistics follow the reference
- Improved representation of **climate indices** based on fixed threshold



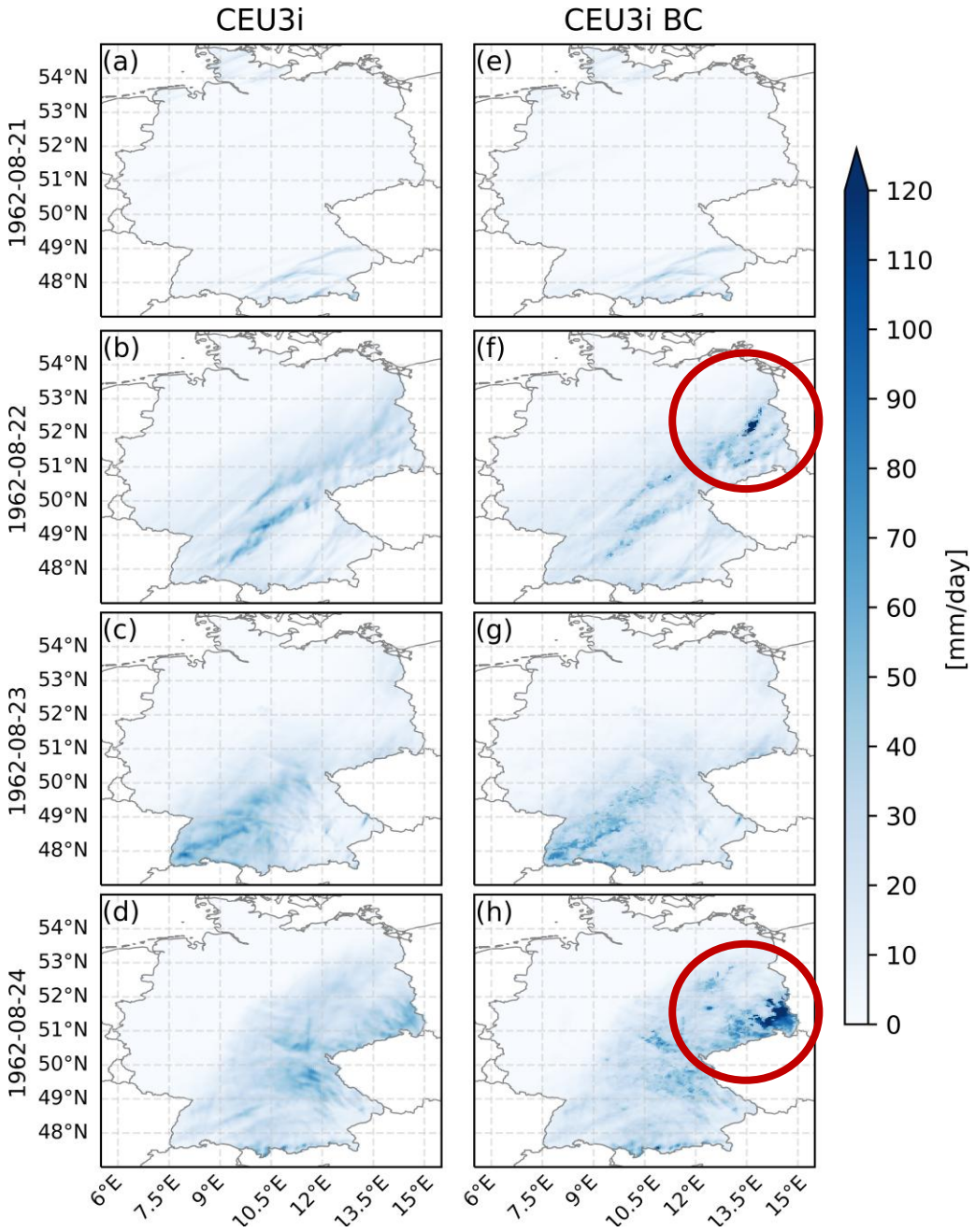


Bias Corrections – Con‘s

- **Event-based analysis** limited:
  - Negative effect on absolute local maxima (too high)
  - Impacts the spatial structure, e.g. strong spatial gradients

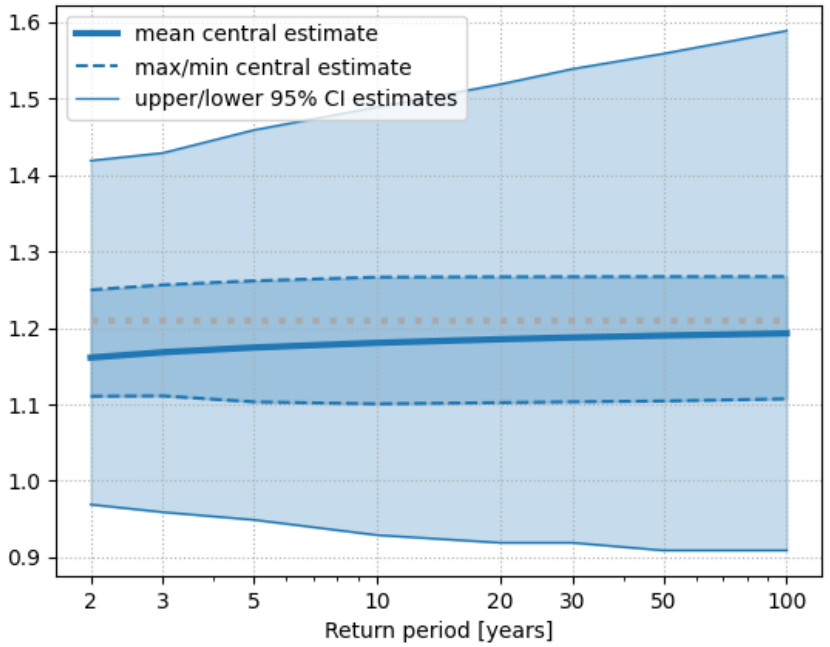


Rx1day GWL3K

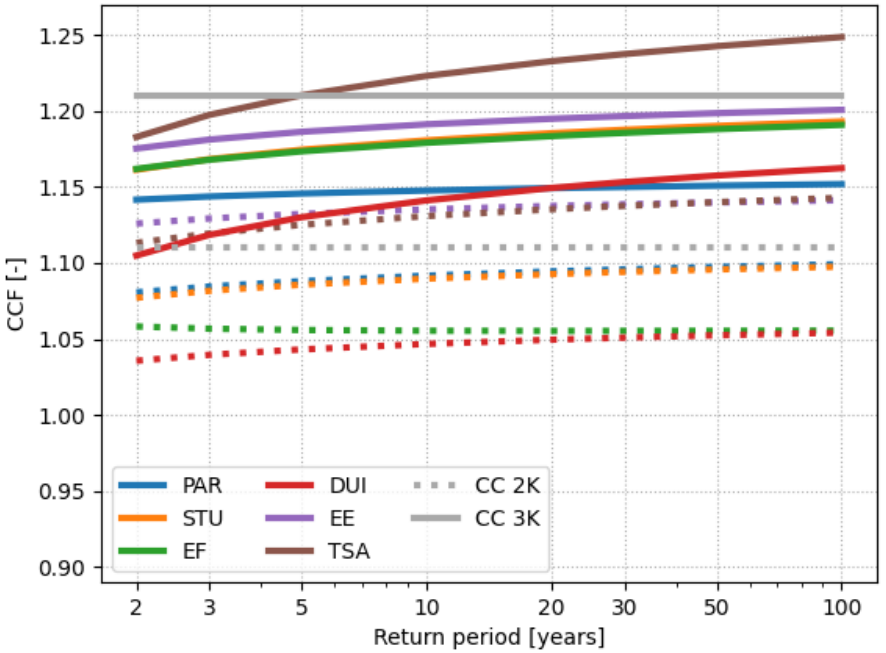


Applications – IDF tool

- Online tool to derive climate change factors (CCF) of **heavy precipitation** statistics
  - **Intensity-Duration-Frequency** curves of hourly precipitation
  - Similarities to DWD-KOSTRA
  - **Pooling** of all NUKLEUS members to increase data basis
    1. Extract 9x9 grid cells around selected coordinate
    2. Pool data at each grid cell by RCM
    3. Fit (90-year) data at each grid cell using GEV
    4. Average CCFs across all 81 grid cells (sorted) and RCMs
- **Output**: central, min, max estimates of CCF for different return periods



STU



Central CCF estimates

Applications – Heating/Cooling Demand

- Heating/Cooling degree-days (**HDD, CDD**) as indicator for the energy demand (sum over time)

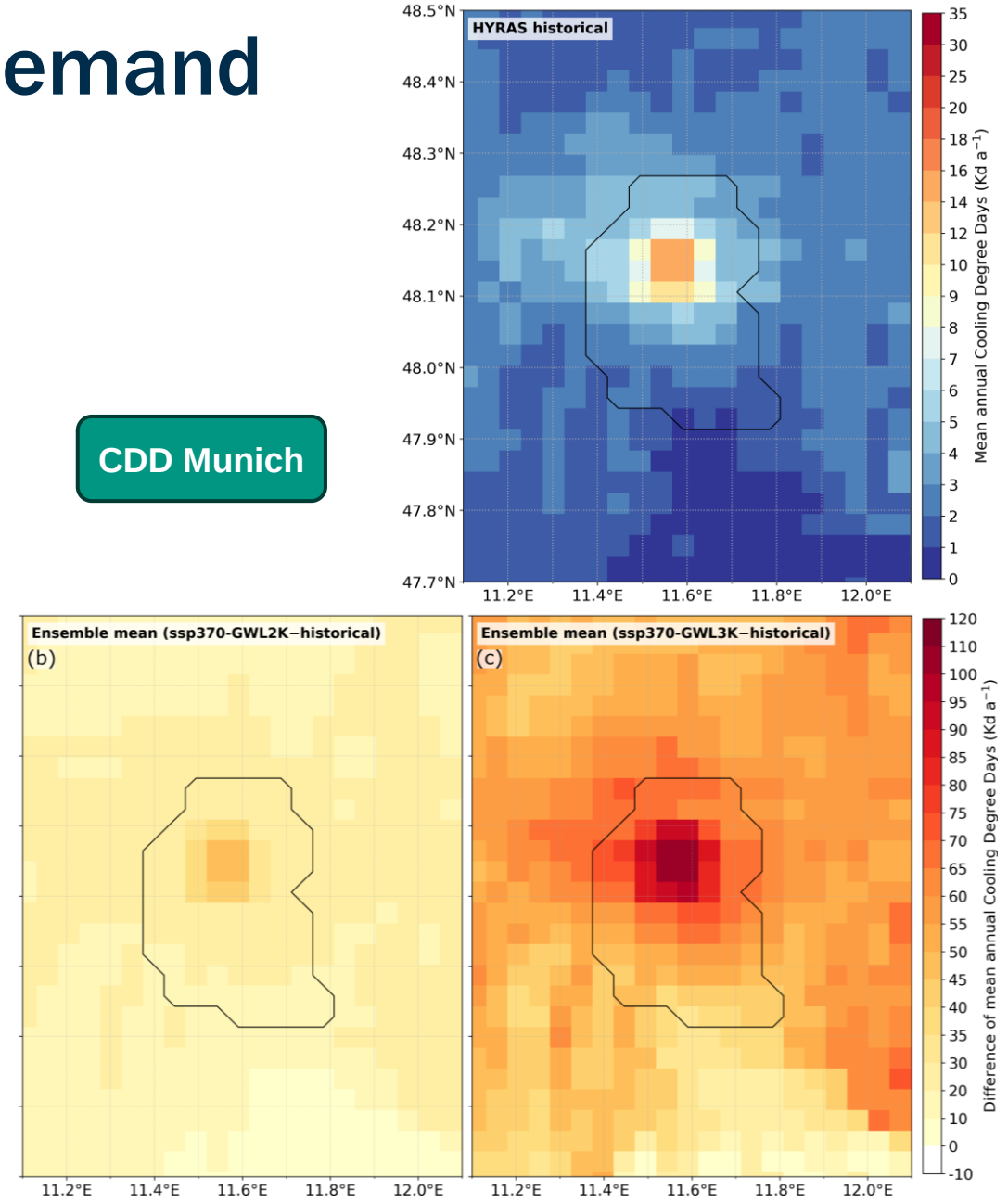
$$\mathrm{HDD} = (20\,^{\circ}\mathrm{C} - T_{\mathrm{m}}) \cdot 1\,\mathrm{d}, \quad \text{if} \quad T_{\mathrm{m}} < 15\,^{\circ}\mathrm{C}$$

$$\mathrm{CDD} = (T_{\mathrm{m}} - 21\,^{\circ}\mathrm{C}) \cdot 1\,\mathrm{d}, \quad \text{if} \quad T_{\mathrm{m}} \geq 24\,^{\circ}\mathrm{C}$$

- Decreasing HDD and even **stronger increase** signal in CDD across Germany
  - Relative change in **higher altitudes** stronger
  - Decrease/increase mainly due to less/more extreme temperatures
  - RCM tend to underestimate local trends vs. HYRAS
- **Robust trends** as all NUKLEUS member (9/9) show same direction
- High resolution (3km) shows **urban-rural contrasts,** even though no specific urban parameterization was used

Ehmele et al. (submission in preparation)

CDD Munich



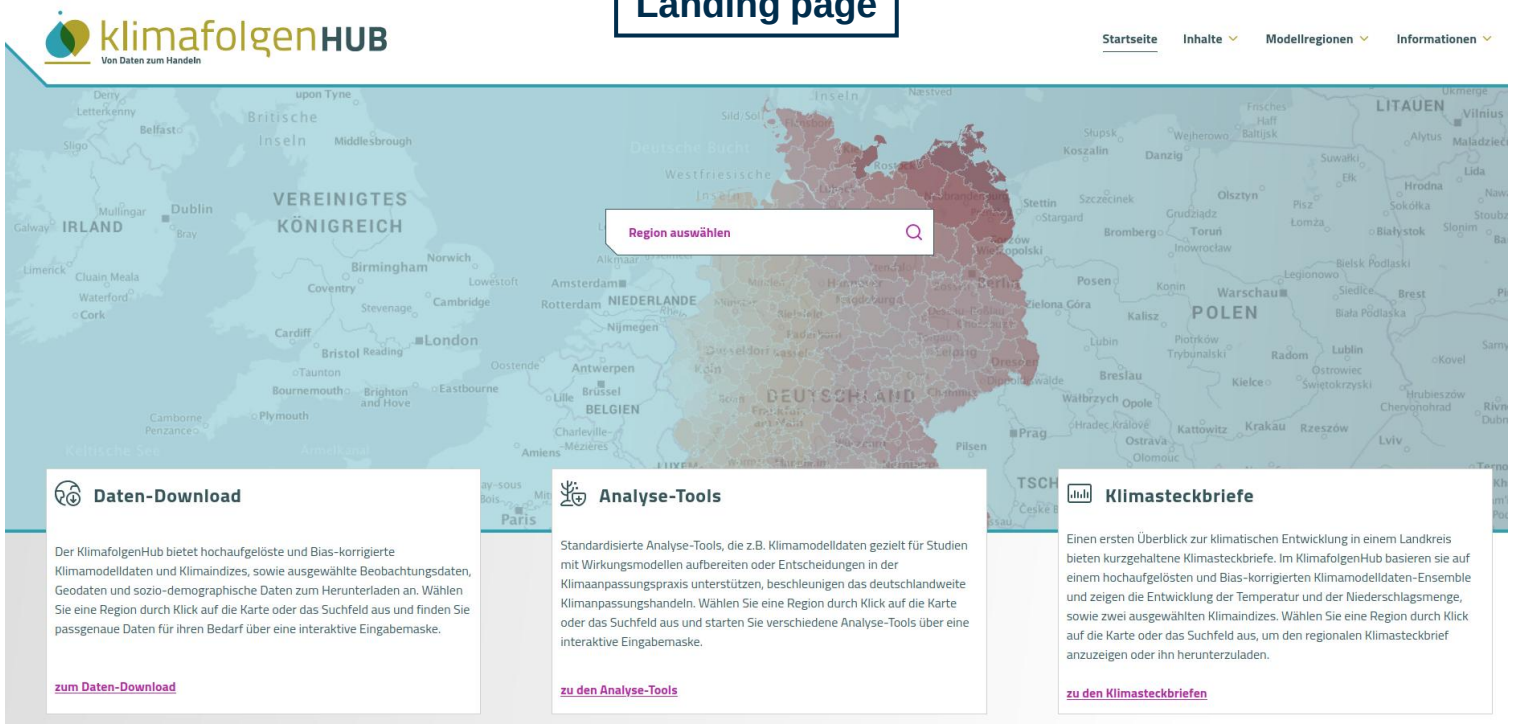
klimafolgenHUB
Von Daten zum Handeln

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

- **Online platform** supporting climate action
  - Providing climate model and observational data sets, **processed user- or application relevant data** (e.g., climate indices), analysis tools, manuals and guidelines
  - **Low-key and non-scientific** information access via data download or online via interactive exemplary visualization
  - **“Expert”-mode** with analysis tools for more advanced information and data
  - In **German** together with **DWD**
  - NUKLEUS and other climate data from DWD and BMFTR projects

Landing page



The **klimafolgenHUB** will be online after the RegIKlim final conference 28/29 September 2026 (some features remain in prototype state)

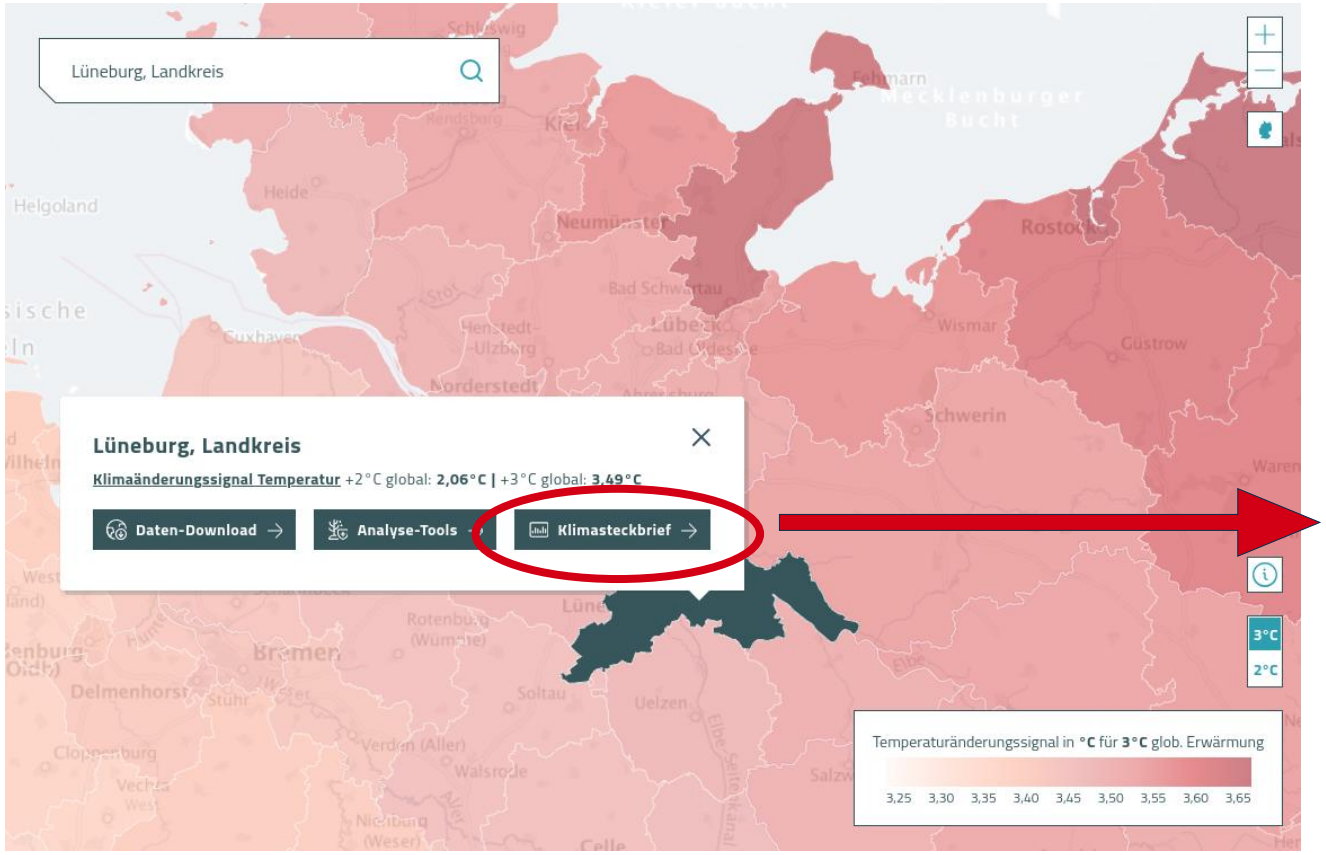
KIT

klimafolgenHUB
Von Daten zum Handeln

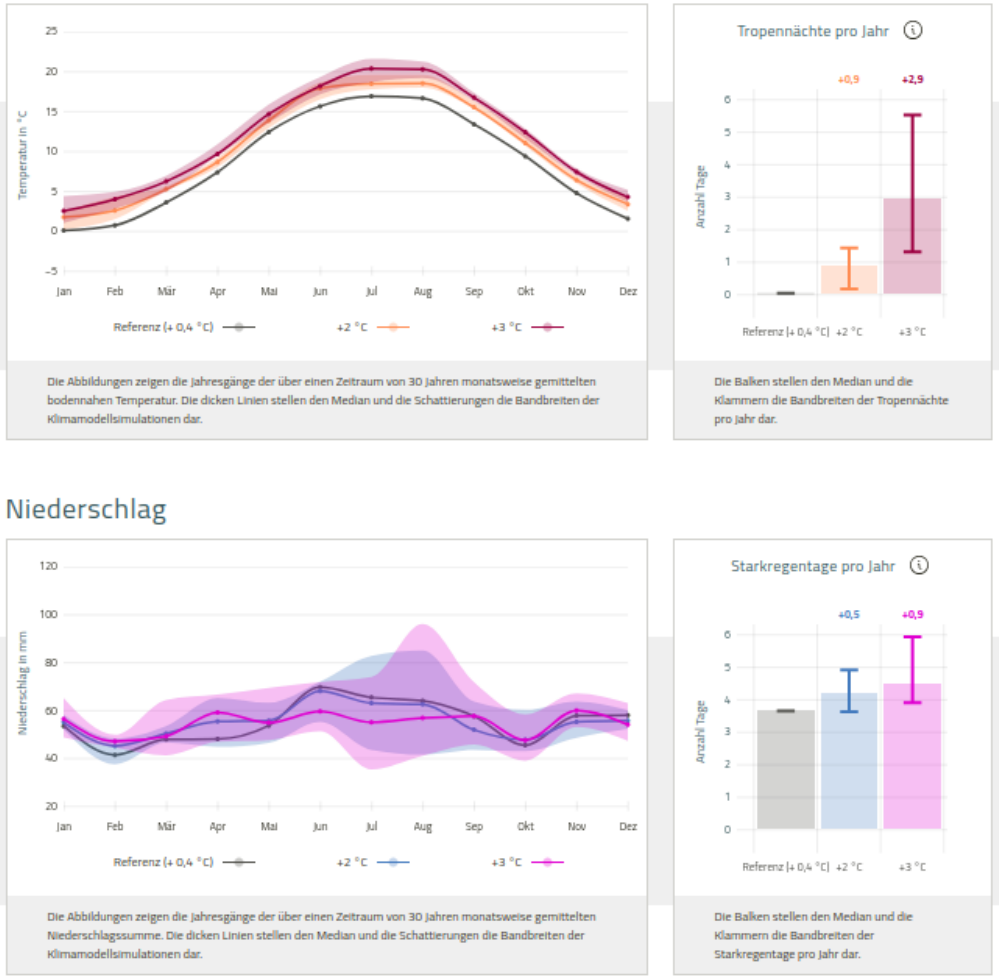
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Interactive map with summary and links to data and tools



Climate fact sheets



Summary & Conclusions

- **High-resolution (3km)** provides unprecedented detailed local climate information, especially in complex terrain, but also urban-rural contrast are detectable even though no particular urban parameterization was used
- **RCMs** modulate the spatial (bias) pattern, while **GCMs** affect the magnitudes
- **Temperature-based analyses** and climate indices more robust than precipitation-based ones
- **QDM bias correction** successfully removes climatological mean bias and preserves climate change signals, but reveals limitations for event-based analysis, such as incoherent fields and “overshooting” of extremes
- Developed **online platform** provides comprehensive **information** on the application of climate data and several user-relevant analysis **data** and **tools** to support (local) adaptation measure and other climate action in Germany

RegIKlim
Regionale Informationen zum Klimahandeln

NUKLEUS
Nutzbare lokale Klimainformationen für Deutschland

klimafolgenHUB
Von Daten zum Handeln



Backup slides

NUKLEUS in the context of other RCM ensembles

Nutzbare lokale Klimainformationen für Deutschland

KIT-KLIWA:

- 4 CMIP5 GCMs downscaled to convection-permitting 2.8km with COSMO-CLM for Central/Southern Germany and Alps
- Same “model families” used but in different versions

Comparison:

- Magnitude of temperature biases in same order
  - GCMs used in KIT-KLIWA but not in NUKLEUS with more extreme warm/cold biases
- Magnitude and spatial pattern of precipitation biases similar in both ensembles
  - Predominantly wet biases especially over mountains
  - GCMs seem driving factor for the precipitation pattern

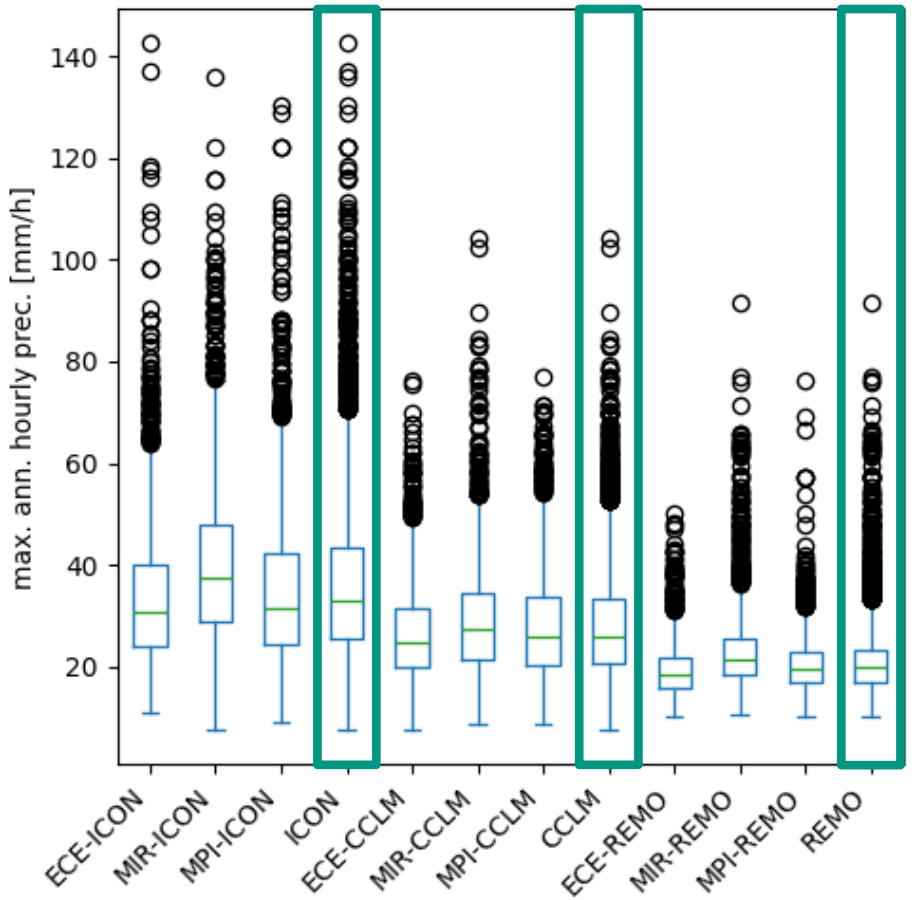
EURO-CORDEX:

- 11 RCMs downscaling 8 CMIP5 GCMs (55 combinations) over Europe at 12km, convection not explicitly resolved (parameterized)
- Same “model families” used but in different versions

Comparison:

- Mainly cold biases in EURO-CORDEX in mountainous regions in winter, NUKLEUS mainly warm biases
- More pronounced dry biases in EURO-CORDEX
- Larger ensemble size leads also to larger range of biases
  - Biases tend to be higher in EURO-CORDEX, especially over complex terrain

Method - step 1: Derive time series of maximum annual hourly precipitation



Select 9x9 grid box (~27 x 27 km²) and **merge data for each regional climate model.**

- 3 x 81 time series with a length of 90 years
- → 21870 years (but largely correlated)
- About 5% uncorrelated
- → ~1000 years
- Done separately for reference period and scenario period

Method analogously after Voit et al., 2026

Method - step 2: Fit data at each grid point for each period and regional climate model

Input

90 year time series

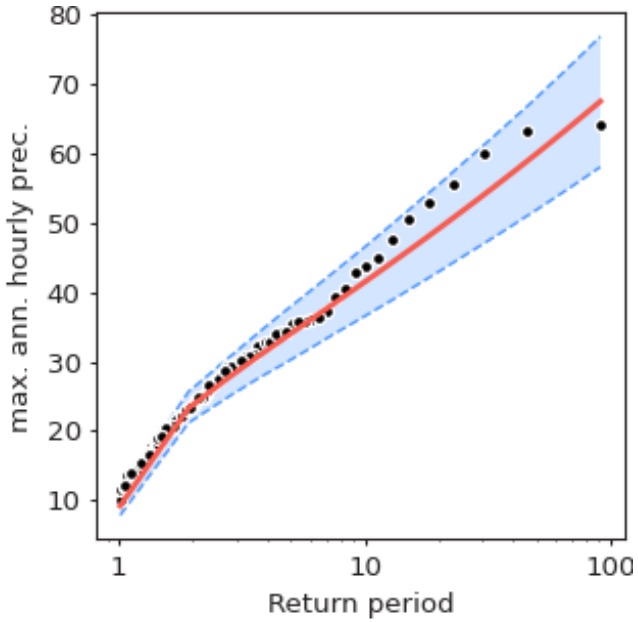
Python package pyextremes*

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

- Generalized extreme value distribution
- G: non-exceedance probability
- z: precipitation intensity
- μ, σ, ξ: location, scale, shape = 0.1
- Bootstrapping for uncertainty estimates

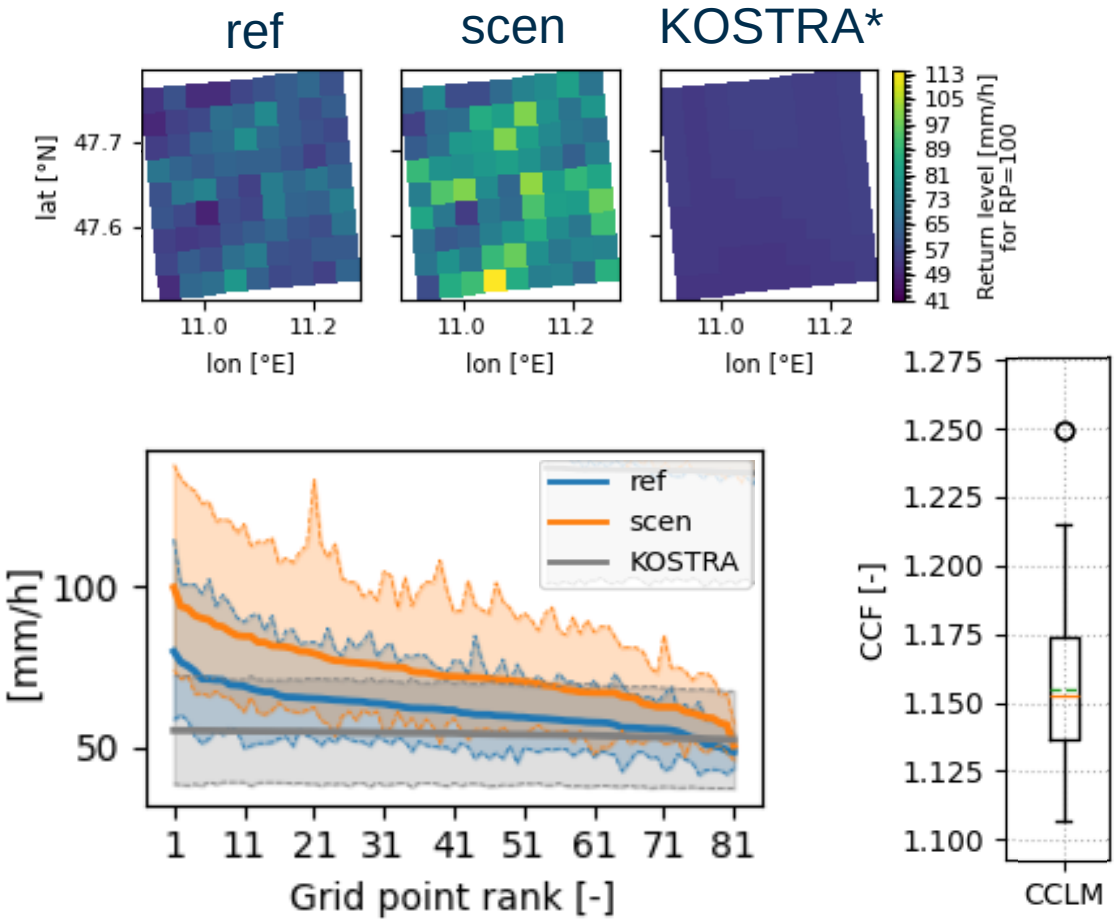
Output

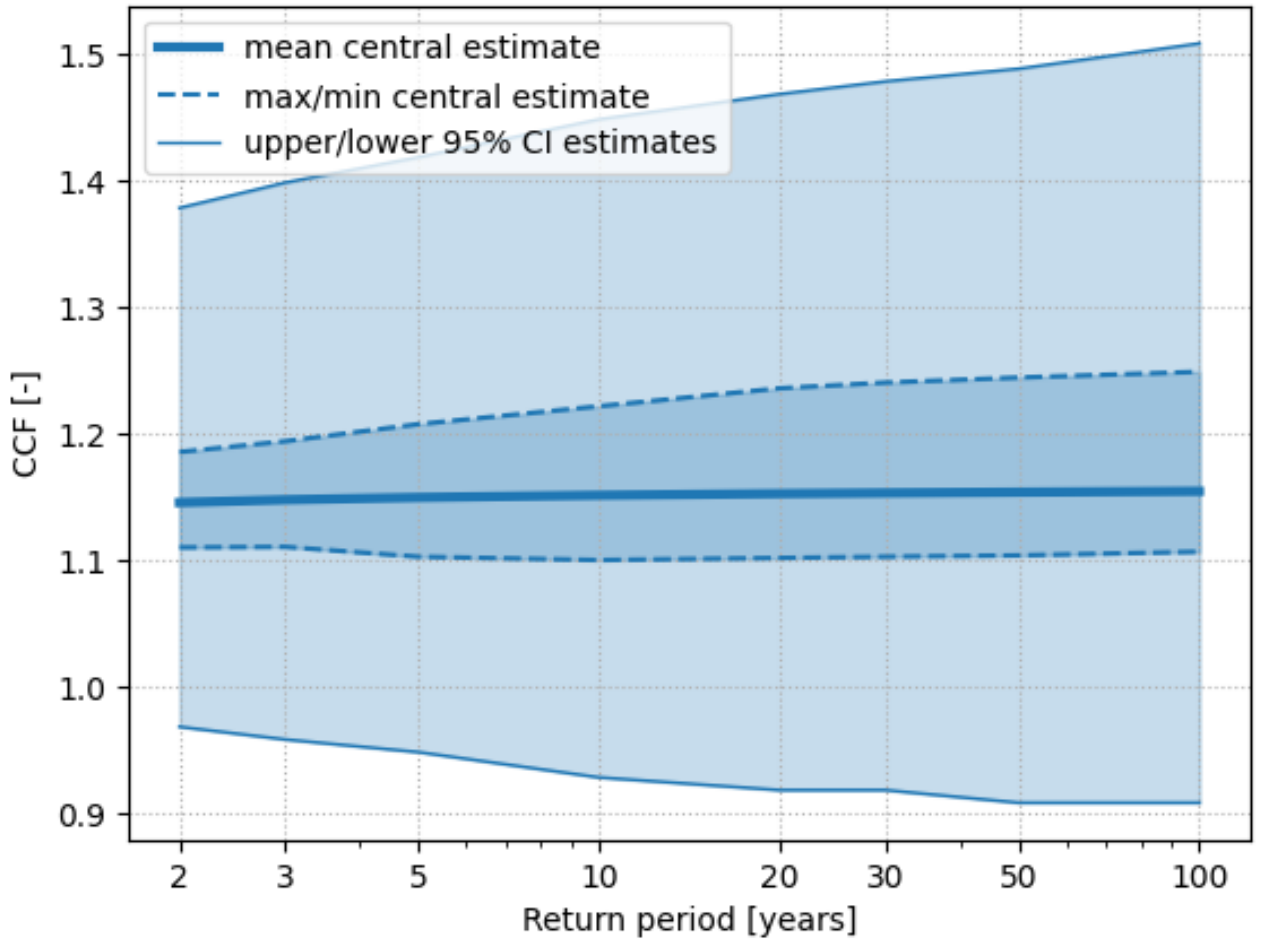
Return values for return periods from 2a to 100a



*https://georgebv.github.io/pyextremes

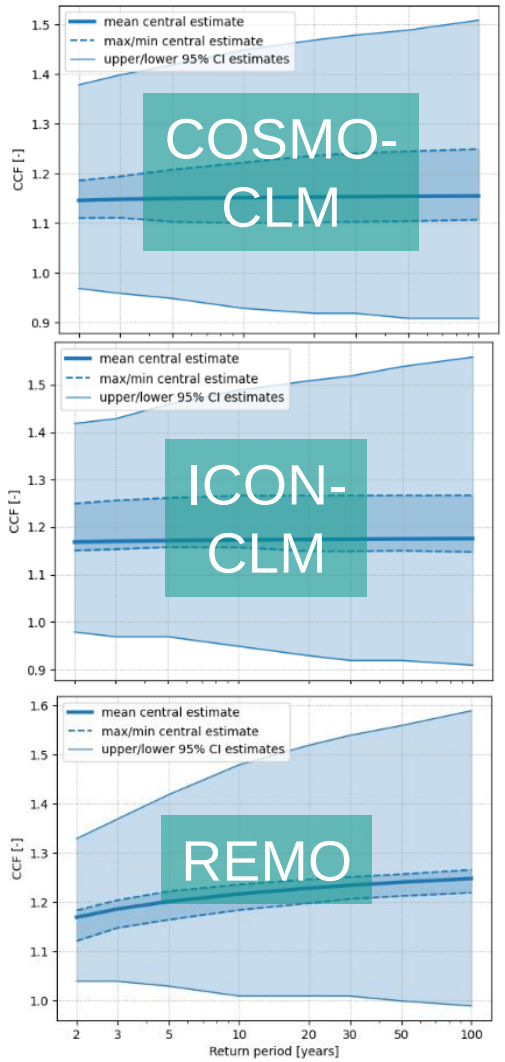
Method - step 3: Calculate climate change factor estimate for each regional climate model



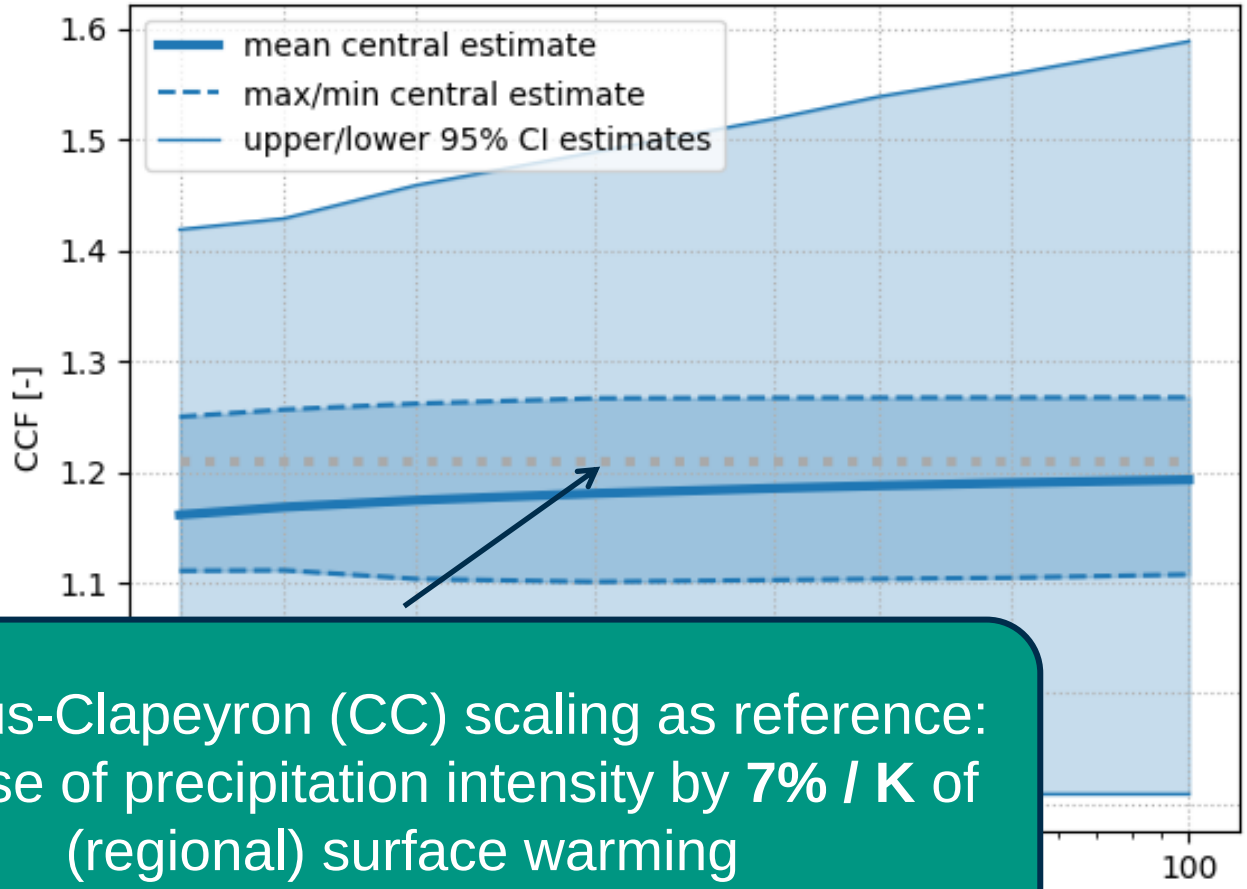


*Coordinated heavy precipitation regionalisation and analysis by DWD

Method - step 4: Deriving ensemble climate change factor estimates

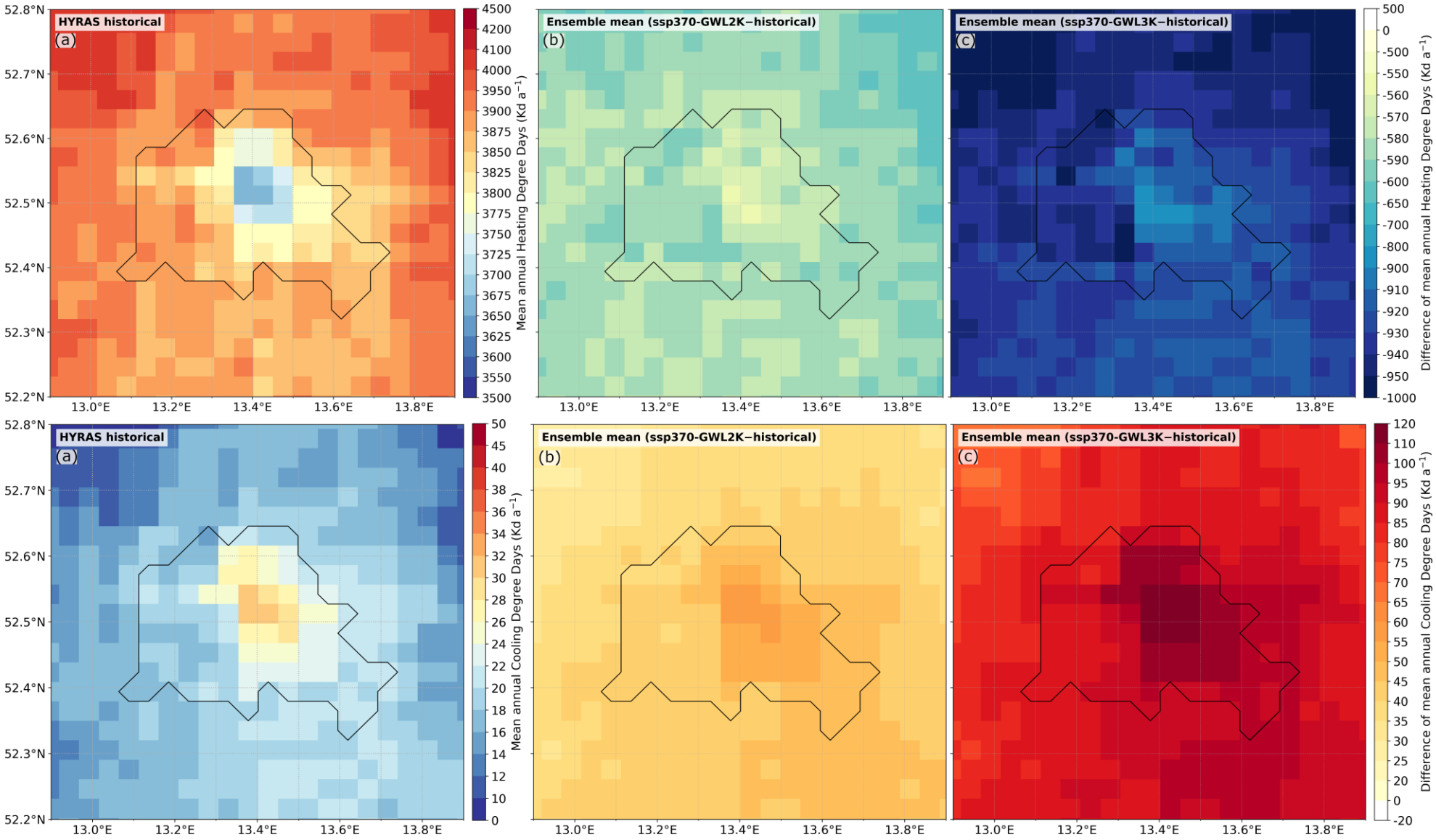


Ensemble



Clausius-Clapeyron (CC) scaling as reference: Increase of precipitation intensity by **7% / K** of (regional) surface warming

Heating/Cooling degree-days



Berlin

HDD

CDD