

Adaptation and Application of the large LAERTES-EU RCM Ensemble for Hydrological Modelling

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Motivation

■ Severe Flood Events

- One of **major hazards** (losses) in Europe
- **Less frequent**
- **Risk** assessment difficult
- **High** uncertainty for most extremes



England Jan/Feb 2014



Central Europe August 2002/June 2013



Siberia June/July 2019

Motivation: Project Story Line

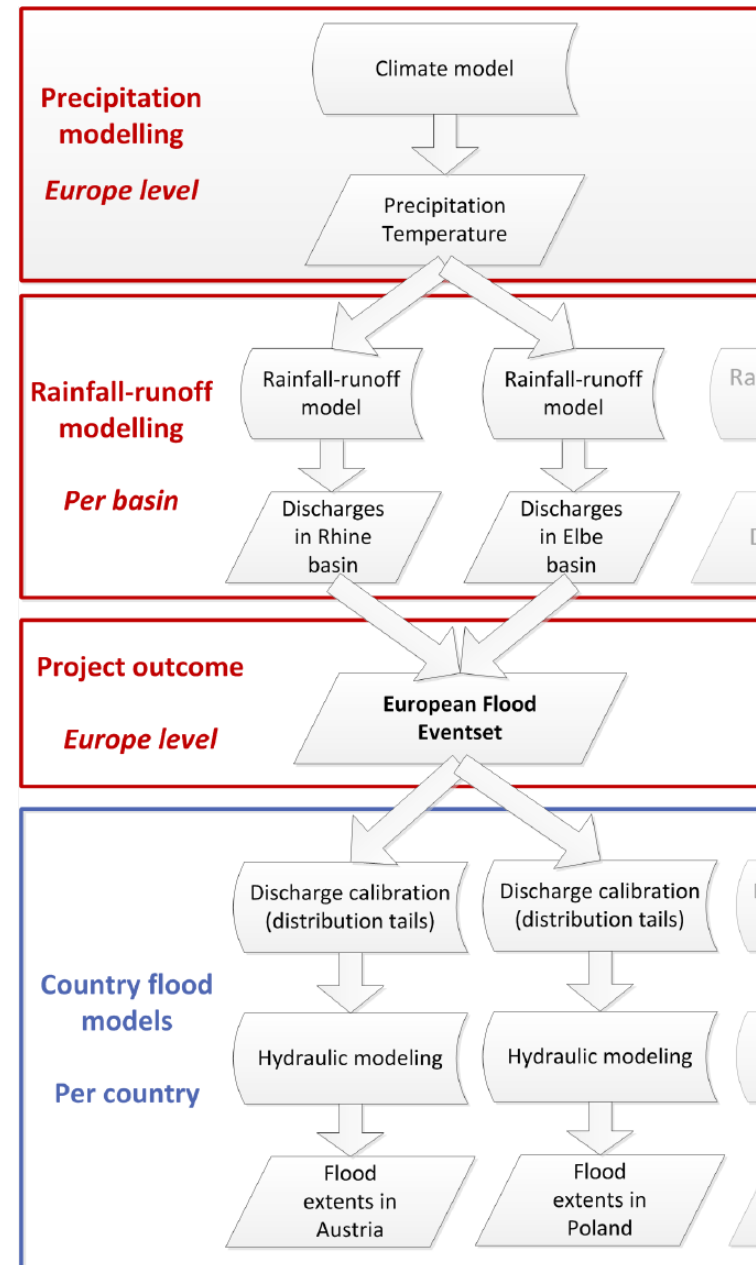
■ Main challenges:

- Time period with **observations too short** to analyze extreme events
- Ground based measurements **spatially heterogeneous**

■ Solution: Huge data sets

- **Here:** Large RCM ensembles
- Others: stochastic weather generators

- Existing risk models (AON) for each country **separately** but not for extreme events affecting several catchments and countries

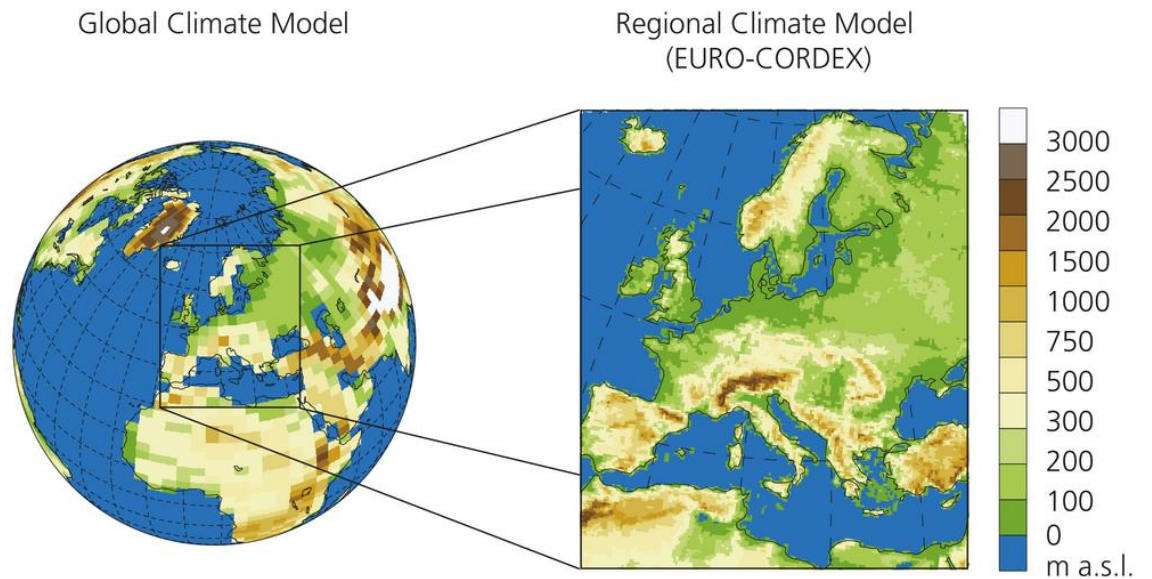


Large Ensemble of Regional climaTe modEl Simulations for Europe

- Dynamical downscaling of GCMs
- EURO-CORDEX region [1]
- COSMO-CLM **25km**
- **daily**

Ehmele et al. (2020): [4]

<https://doi.org/10.5194/esd-11-469-2020>



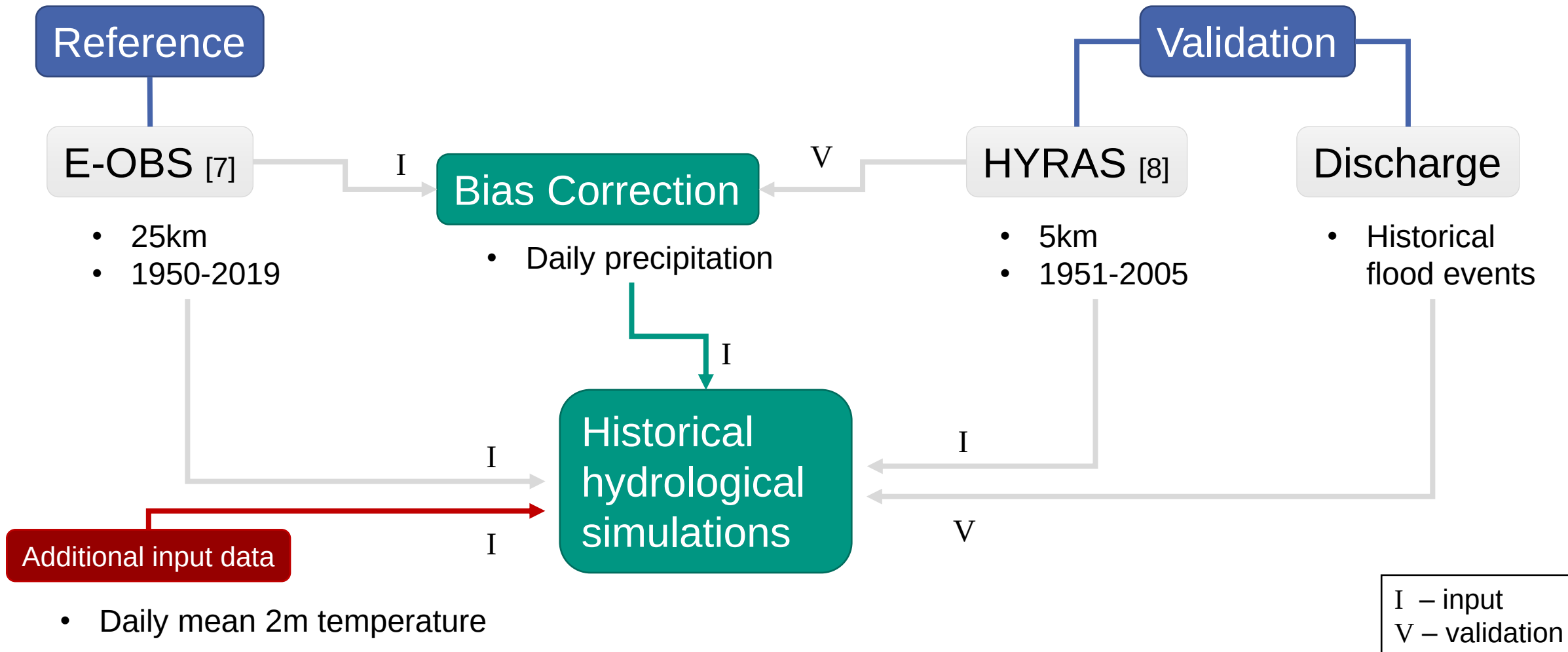
© National Centre for Climate Services (NCCS), Switzerland [3]

LAERTES-EU

- Approx. **1200** simulation runs with approx. **12.500** simulated years
- Dry-day adjustment [5],[6]
 - Drizzle correction
- Bias Correction

	Data Block 1	Data Block 2	Data Block 3	Data Block 4
forcing	20CR via MPI-ESM-LR	MPI-ES-LR droughtclip	MPI-ESM-HR historical	(a) MPI-ESM-HR CMIP5 (b) MPI-ESM-HR CMIP6
period	1900-2009	1910-2019	(a) 1900-2005 (b) 1960-2005	(a) 1960-2026 (b) 1960-2028
type	Long-term	decadals	Long-term	decadals
members	3	3 (100 decades)	(a) 3 (b) 2	(a) 5 (57 decades) (b) 10 (59 decades)

Observational datasets and application



Bias Correction

■ Quantile Mapping

■ Gamma Distribution

■ Cumulative Density Function F

$$P_{BC} = F_{obs}^{-1}(F_{RCM}(P_{RCM}))$$

■ Grid point based

■ Monthly differentiated

■ One function for each data **block**



Preserve natural Variability of different model realizations

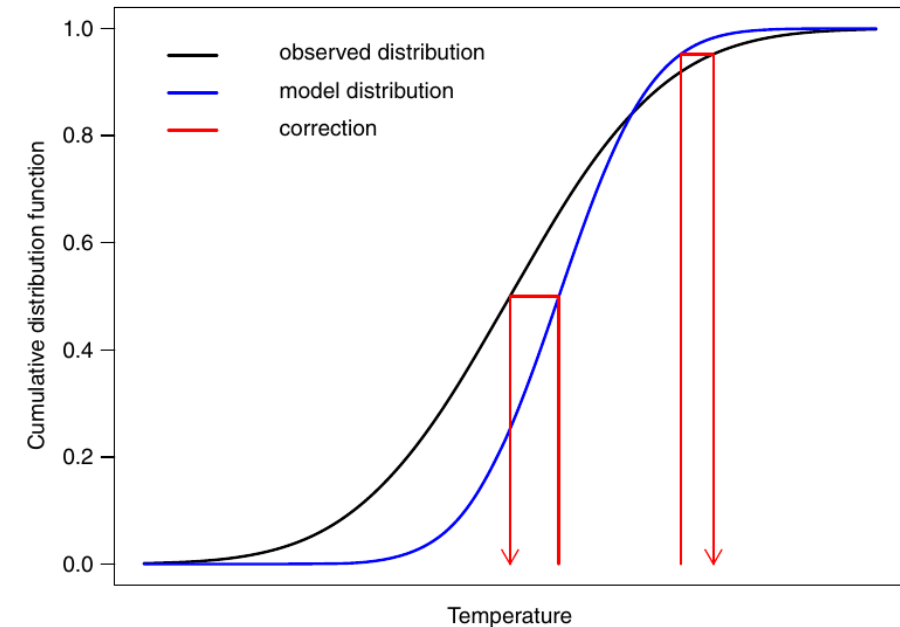
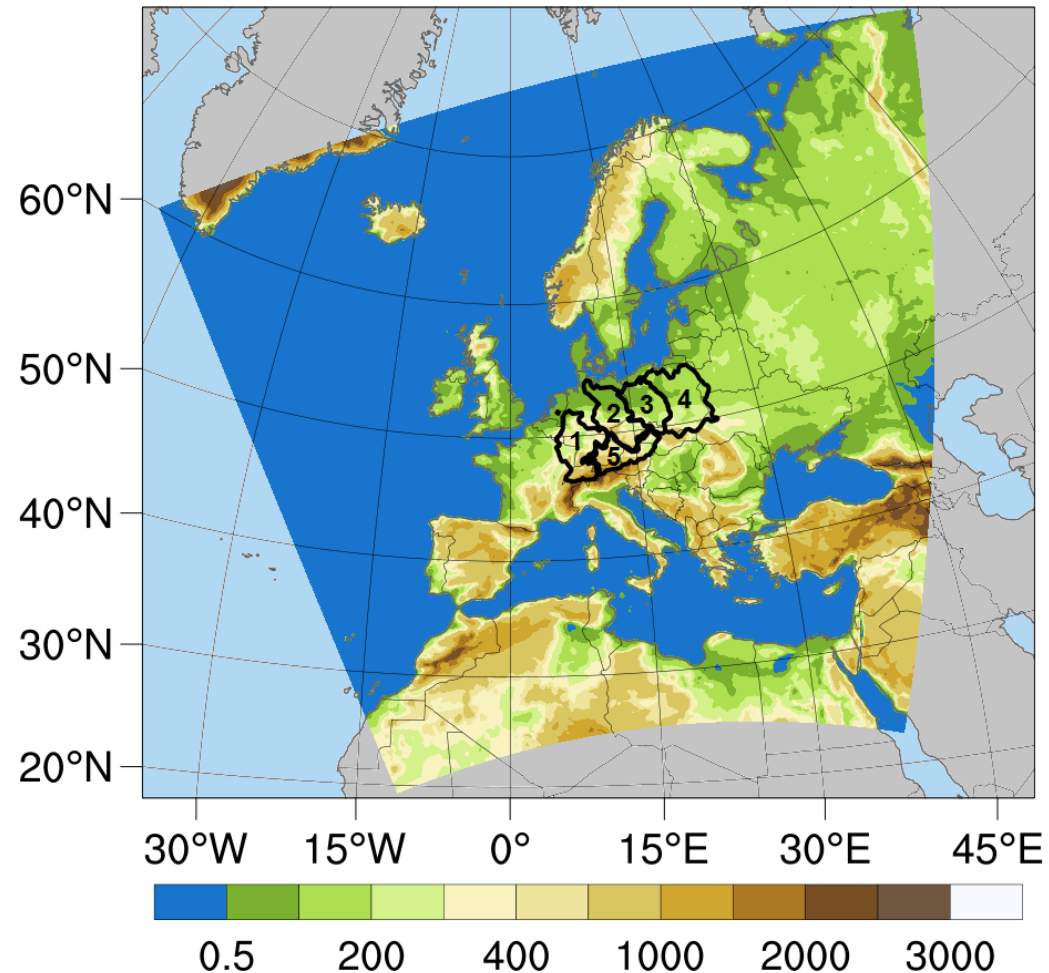


Fig. 2 Quantile mapping. A simulated value, a quantile of the simulated distribution, is replaced by the quantile of the observed distribution corresponding to the same probability

(Maraun, 2016) [9]

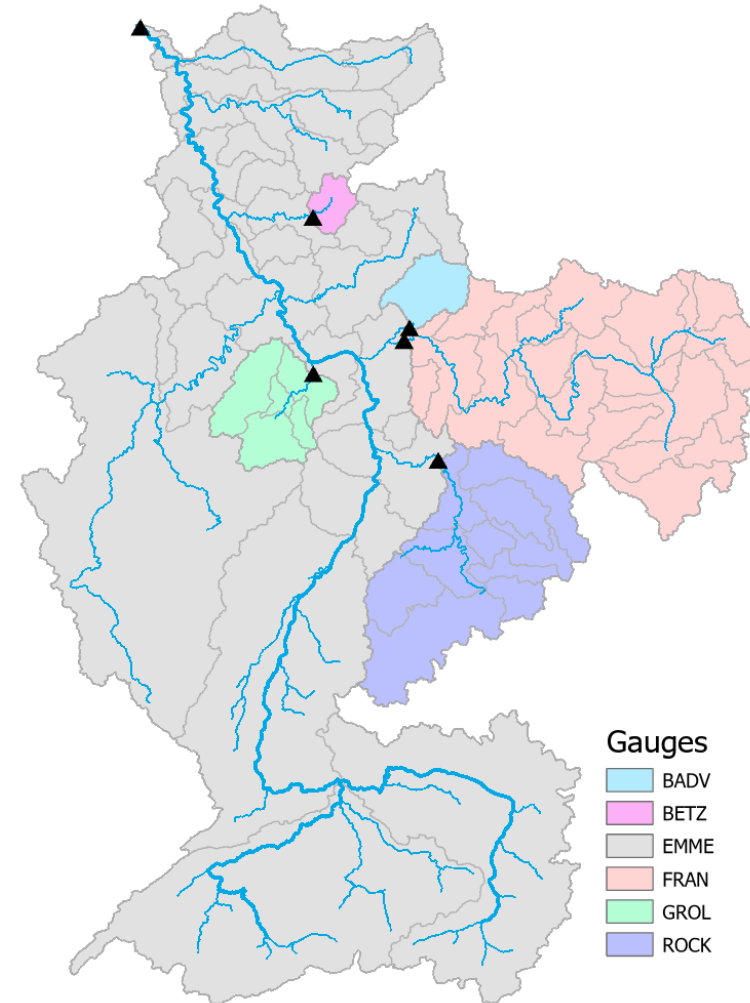
Investigation area



- Major River Basins
 - Rhine (1) → Pilot area (best data availability)
 - Elbe (2)
 - Oder (3)
 - Vistula (4)
 - Upper Danube (5)

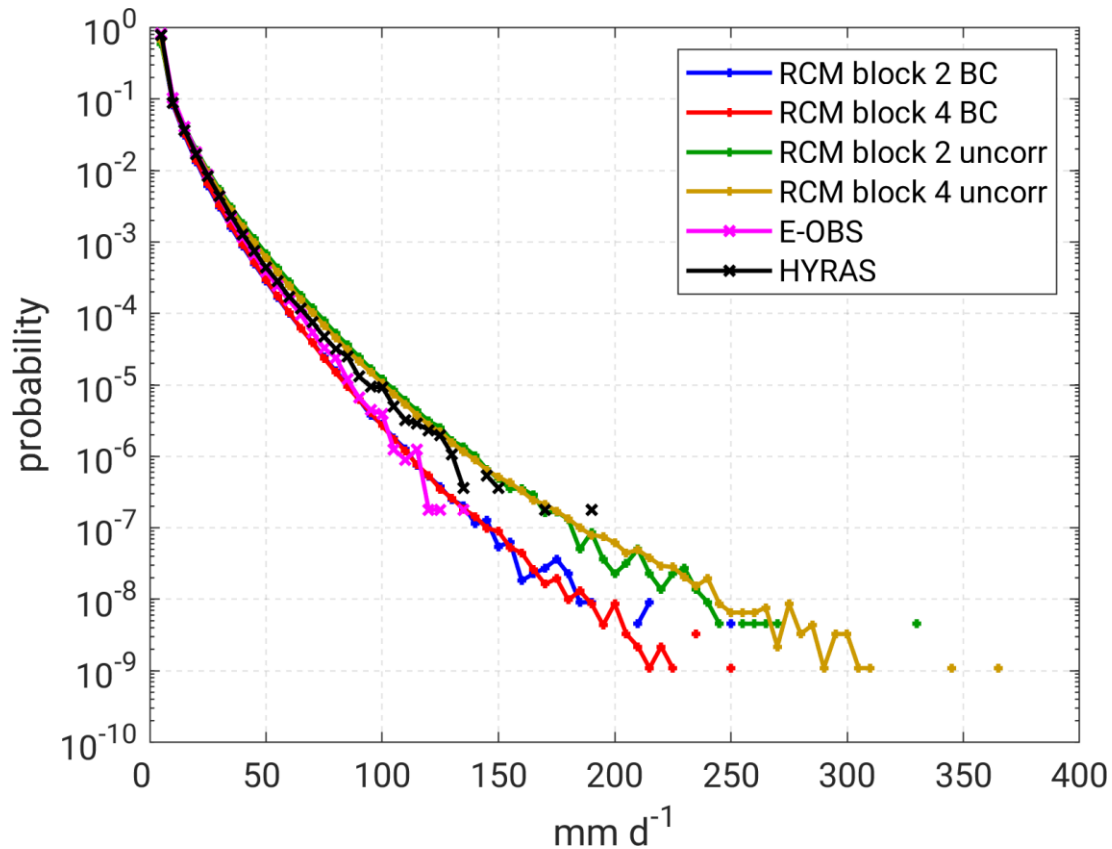
Pilot area: Rhine basin

- Catchment **area**: ~ 185,000 km²
- River **length**: ~1200 km
- Mean **discharge** near estuary : ~2100 m³/s
- Main **reference** discharge gauges:
 - **Emmerich** (EMME)
 - Frankfurt (FRAN)
 - Rockenau (ROCK)
 - Grolsheim (GROL)
 - Bad Vilbel (BADV)
 - Betzdorf (BETZ)

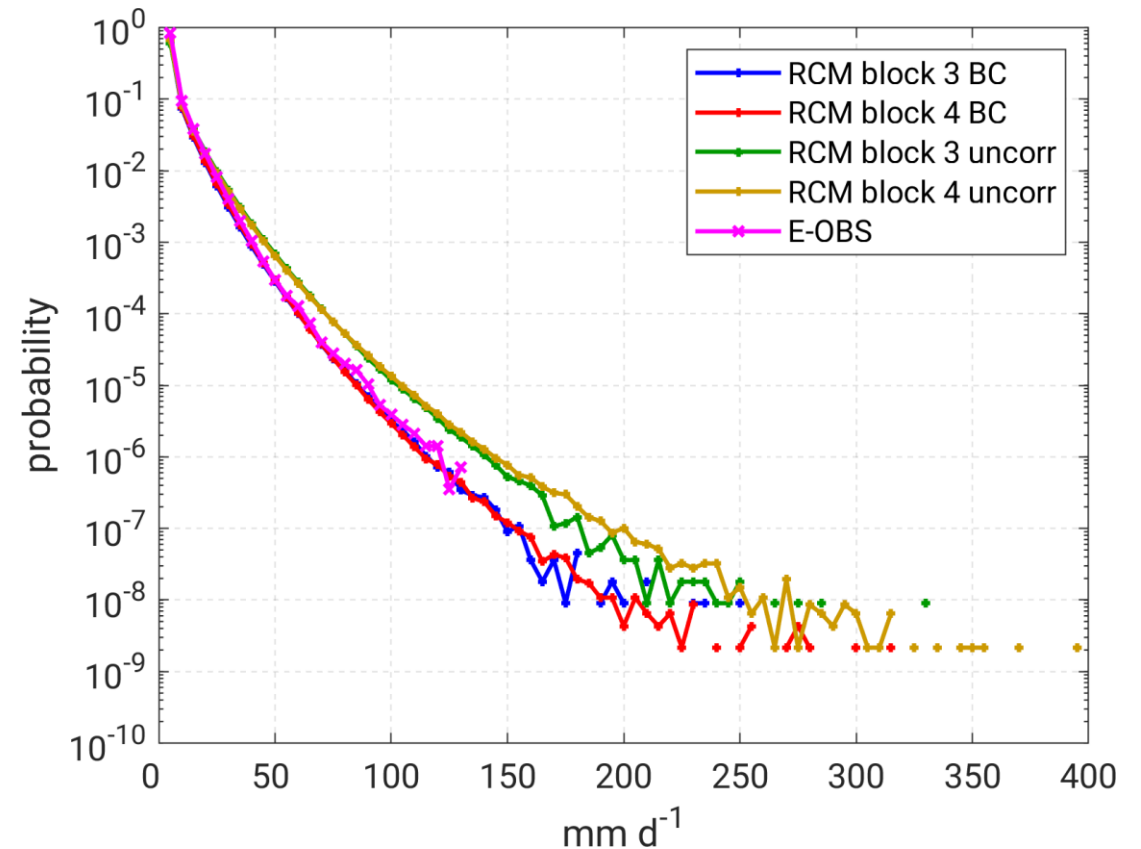


Precipitation: Distribution of daily totals (grid point based)

Rhine basin

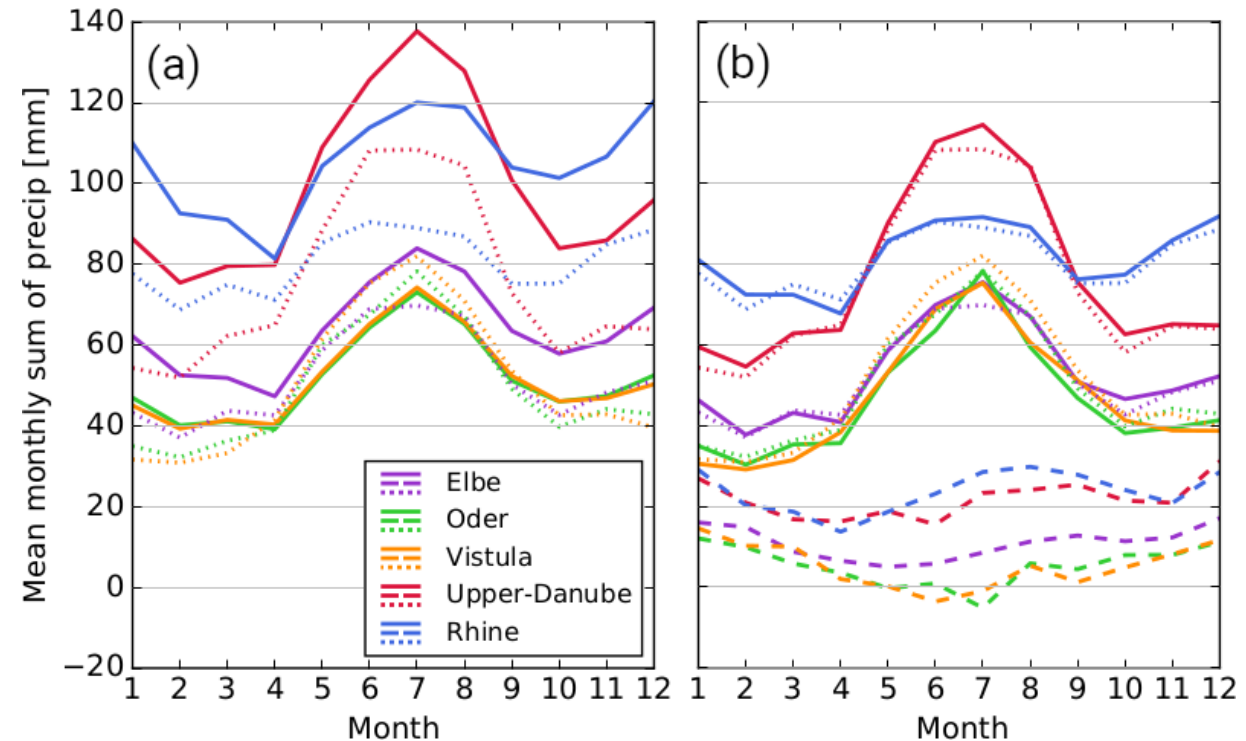


Upper Danube basin



Precipitation: Annual Cycle of spatial means

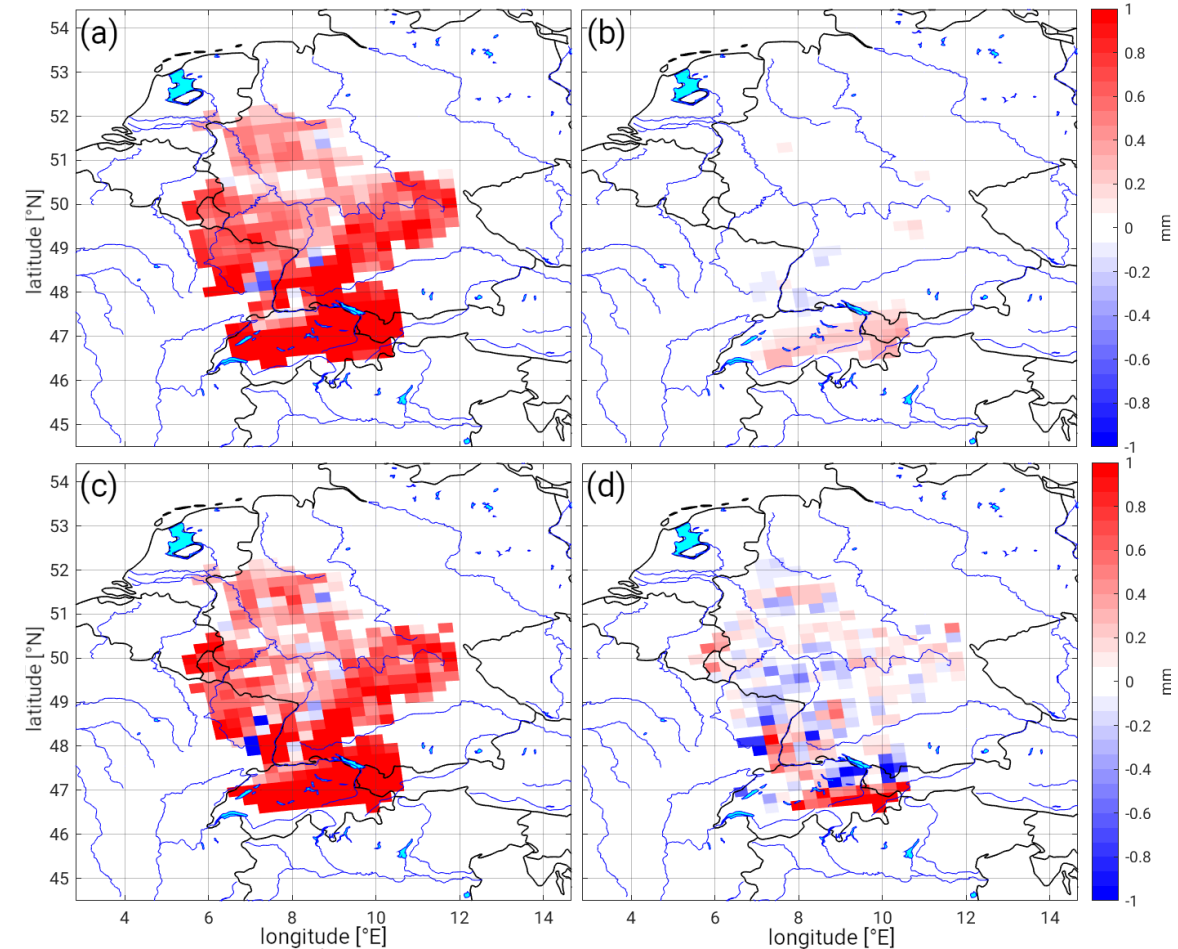
- **Overestimation** by raw RCM
- Positive bias stronger in **mountainous** terrain (Rhine & Upper Danube)
- Stronger adjustments in **winter**
- **Bias correction** preserves annual cycle



Solid: raw RCM data
dotted: E-OBS
dashed: difference raw – bias-corrected

Precipitation: Spatial Bias

- Mainly **positive bias** (ensemble mean) of uncorrected data
- Positive but strongly reduced bias remains in **mountainous regions**
- Negative bias towards HYRAS after correction
→ E-OBS with negative bias towards HYRAS, too



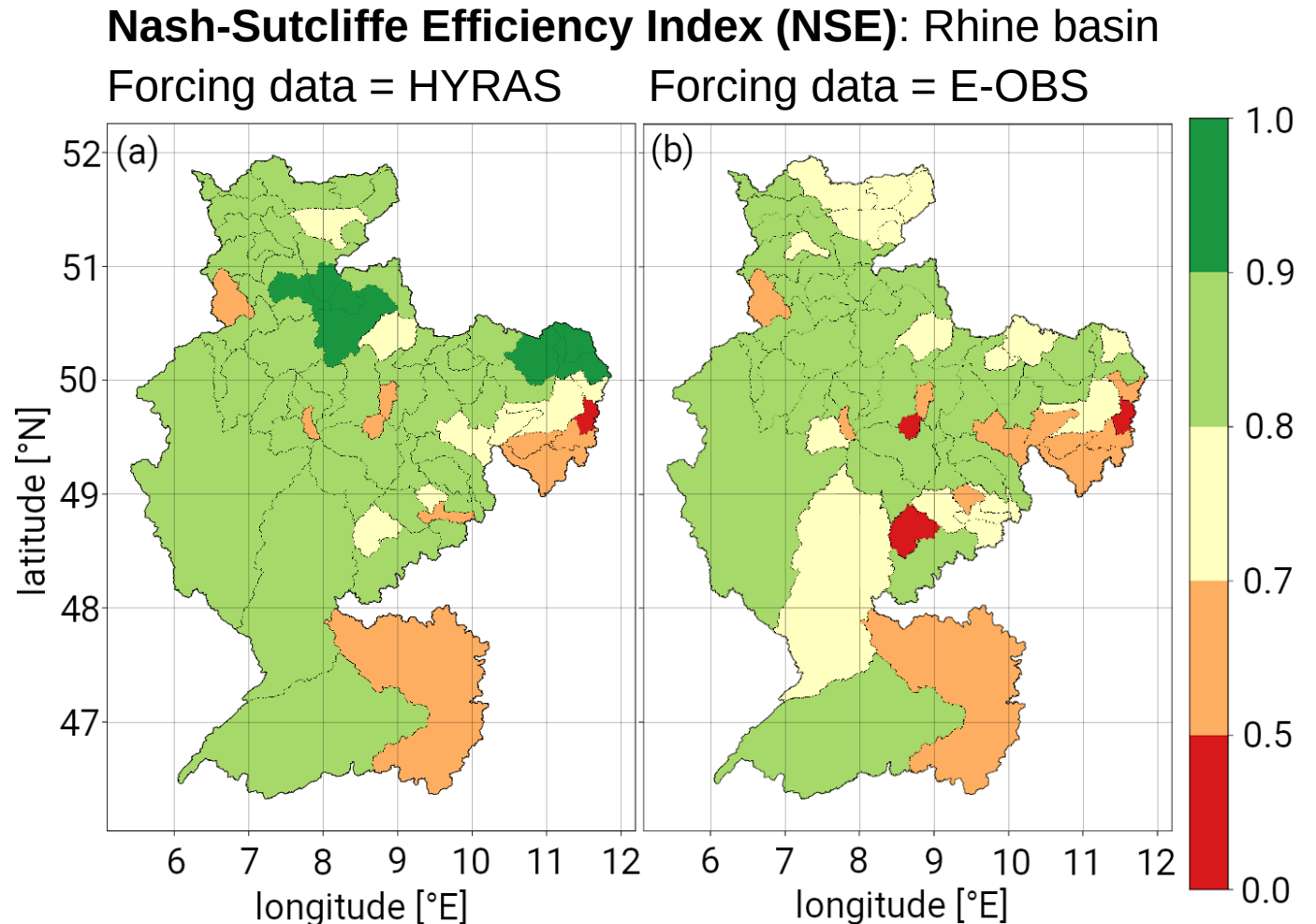
Bias (ensemble mean) of daily totals towards E-OBS (top) and HYRAS (bottom) of uncorrected (left) and bias-corrected (right) precipitation.

Hydrological Model

- Hydrologiska Byråns Vattenbalansavdelning (**HBV**) model approach [10]
 - Conceptual model
 - Here: HBV-IWS [11]
 - Adjusted for spatial/gridded input data
 - **Input** data: Daily precipitation and daily mean 2m temperature
 - 4 internal **routines**:
 - Snow melt and accumulation
 - Soil moisture and effective precipitation
 - Evapotranspiration (calculated from input data)
 - Runoff response
 - **Triangular** weighting for surface routing delay
 - **Muskingum** routing for upstream -> downstream flow calculation

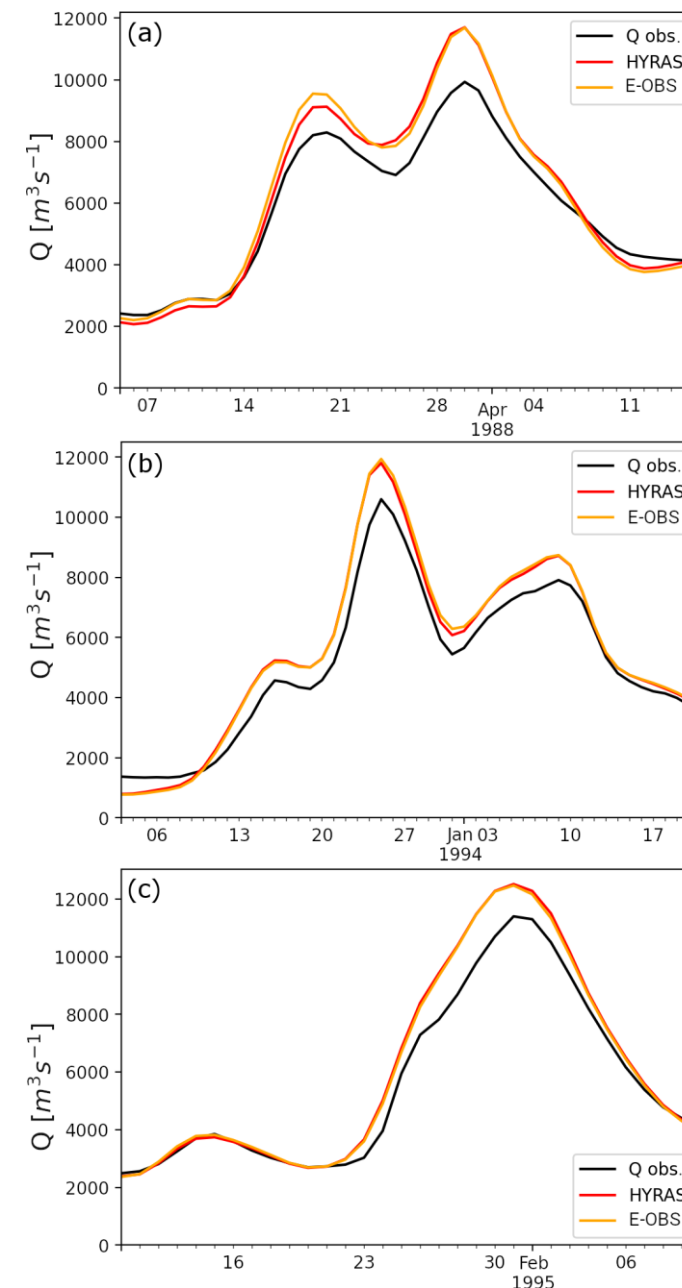
Hydrological Model: Validation

- **Forcing data:** gridded observations
- Simulated discharge overall matches well with observations even for small catchments with little exceptions even at 25km resolution
- Southeast sub-catchment includes Lake Constance → buffer for flood peaks, lakes not directly implemented in the HBV approach



Historical Flood Events

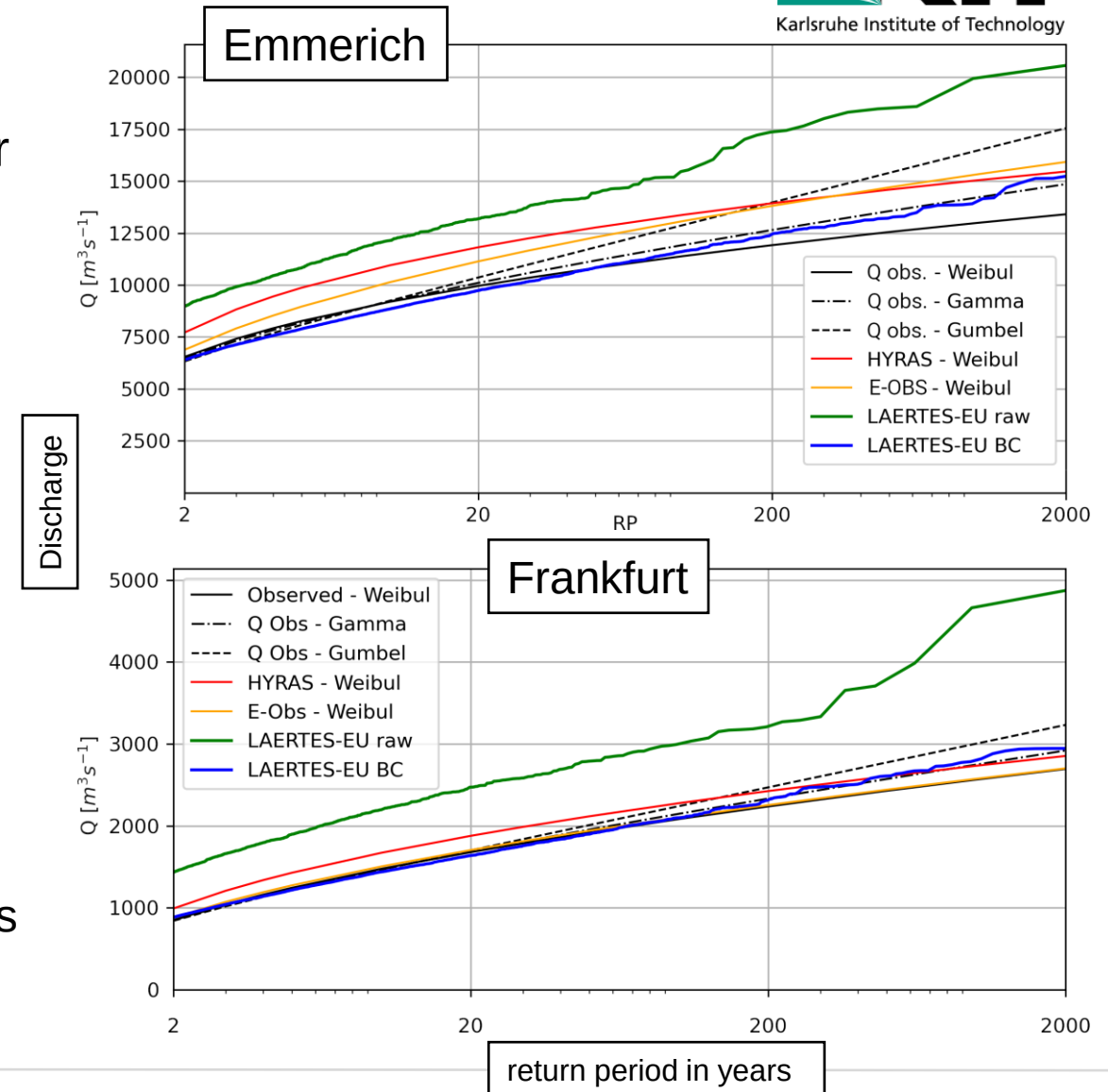
- **Forcing data:** gridded observations
- **Peak discharge:**
 - Timing well represented also multi-peaks
 - Overestimation compared to observed discharge → calibration
 - Winter floods: uncertainties from insufficient data base of snow melt and soil water storage
 - Timing errors in smaller catchments (not shown) arise from daily resolution → higher sensitivity of small catchments on shorter time scales



Discharge Q
at Emmerich
station

Discharge Statistics

- **Observations** (discharge & precipitation) only for couple of decades maximum
 - **extrapolation** to higher return periods using statistical distributions (Gumbel, Weibull, Gamma)
 - Relatively large **uncertainties (spread)**
- Simulations with observed precipitation
 - Discharge of low return period overestimated → rainfall-runoff response too strong
- **Raw RCM data**: large positive bias
- **Bias-corrected RCM data**:
 - Within uncertainty range of extrapolated observations
 - High number of events with very high return periods included → more **robust estimates**



Conclusions

■ Precipitation Data

- Improved representation of precipitation (intensity & spatial distributions)
- Bias mainly remains in mountainous regions due to coarse resolution
- Bias correction preserves characteristics like annual cycle

■ Hydrological Model

- Long-term analysis (NSE) with good agreement to observed discharges
- Historical flood events (peak discharge) well represented in term of timing
- Errors (e.g., in smaller catchments) arise from coarse temporal & spatial resolution → reduction by calibration

■ Added Value of bias-corrected LAERTES-EU for Hydrological Modelling and further applications

- Reduced uncertainty of extrapolated observed distributions
- More robust estimates of discharge even for very high return periods
→ important, e.g., for insurance industry and risk assessment
- RCM provide physical consistent additional input variables such as 2m temperature

References

- [1] <https://euro-cordex.net/>
- [2] <https://fona-miklip.de/>
- [3] <https://www.nccs.admin.ch/nccs/en/home/climate-change-and-impacts/swiss-climate-change-scenarios/understanding-climate-change-scenarios.html>
- [4] Ehmele et al. (2020): <https://doi.org/10.5194/esd-11-469-2020>
- [5] Feldmann et al. (2008): <https://doi.org/10.1127/0941-2948/2008/0295>
- [6] Berg et al. (2012): <http://doi.org/10.1016/j.jhydrol.2012.04.026>
- [7] Haylock et al. (2008): <https://doi.org/10.1029/2008JD010201>
- [8] Rauthe et al. (2013): <https://doi.org/10.1127/0941-2948/2013/0436>
- [9] Maraun (2016): <https://doi.org/10.1007/s40641-016-0050-x>
- [10] Lindström et al. (1997): [https://doi.org/10.1016/S0022-1694\(97\)00041-3](https://doi.org/10.1016/S0022-1694(97)00041-3)
- [11] He et al. (2011): <https://doi.org/10.1016/j.jhydrol.2011.09.042>