Evaluation of high-resolution river discharge over Europe based on the ICON-CLM climate ensemble simulations

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Gefördert durch:

Bundesministerium für Forschung, Technologie und Raumfahrt

UDAG

Updating the Data basis for Adaptation to climate change in Germany

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Experiment setup

Aim

- Evaluation of simulated discharge and trends in the historical period

Experiments

- Cordex-Europe 11 km: ICON-CLM hindcast + 6 historical simulations
- HD model used to calculate daily discharge from 6-hourly ICON-CLM surface and subsurface runoff at 1/12° (~8 km) spatial resolution.
- Direct human impacts on river runoff are not regarded by the HD model

Publication

- Hagemann et al. (2026) *Environ. Res.: Clim.*, accepted, doi: 10.1088/2752-5295/aea9bc

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HD model and ICON-CLM experiments

HD experiment	ICON experiment	ICON CLM forcing	Period
HD5-EVAL	ICON-CLM EVAL	ERA5	1950-2024
HD5-ECE	ICON-CLM ECE	EC-Earth3-Veg	1950-2014
HD5-CNRM	ICON-CLM CNRM	CNRM-ESM2-1	1950-2014
HD5-MPI	ICON-CLM MPI	MPI-ESM-1-2-HR	1950-2014
HD5-MIROC	ICON-CLM MIROC	MIROC6	1950-2014
HD5-CMCC	ICON-CLM CMCC	CMCC-CM2-SR5	1950-2014
HD5-NOR	ICON-CLM NOR	NorESM2-MM	1950-2014

Experiment	Atmospheric forcing	HydroPy resolution	Period
HD5-ERA5	ERA5	~0.28°	1940-2024
HD5-EOBS31	EOBS31	0.1°	1950-2024
HD5-Hpy-EVAL	ICON-CLM EVAL	1/12°	1950-2024

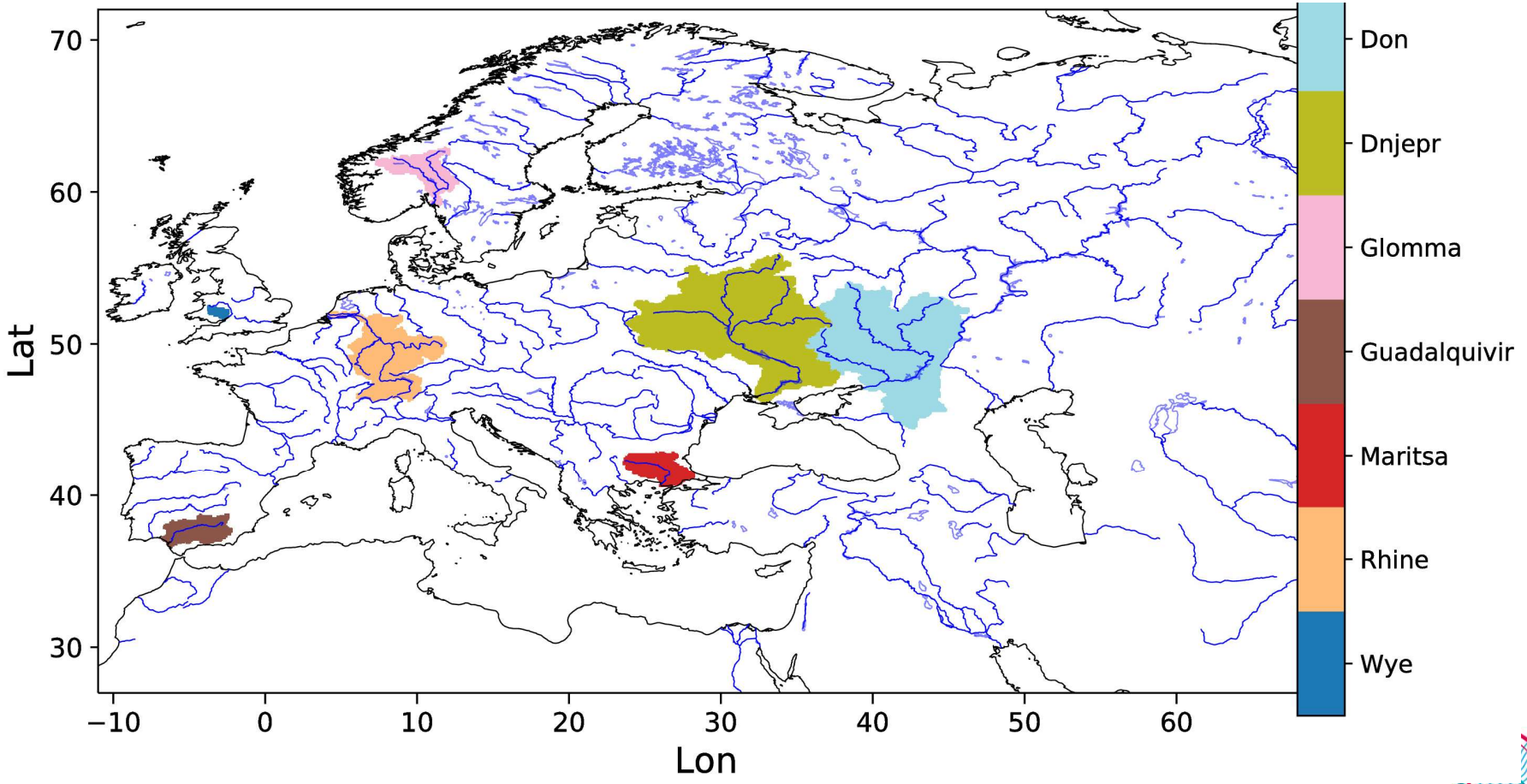
HydroPy forcing vars.: *Precipitation, 2 m temperature*, downwelling shortwave and longwave radiation, 2 m specific humidity, surface pressure, 10 m wind.

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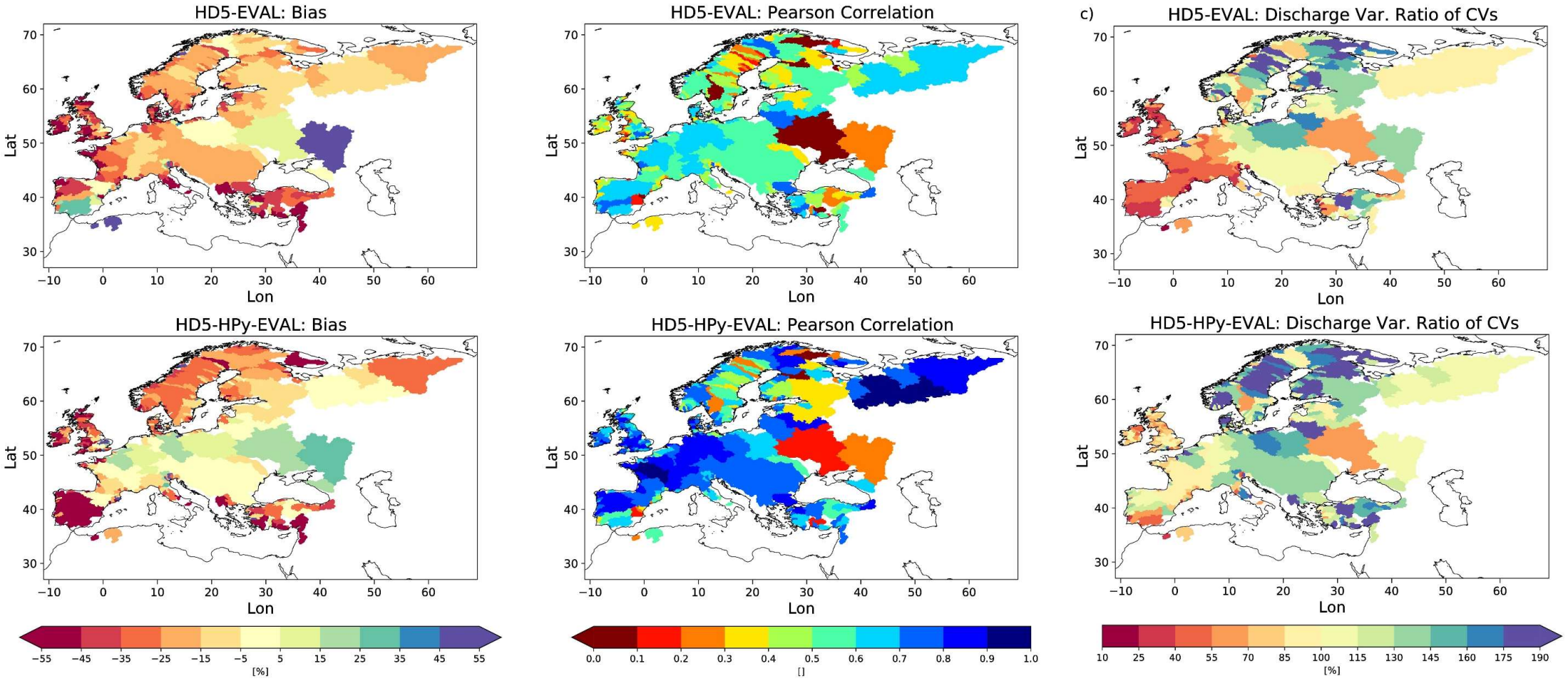
Methods

- Discharge evaluation metrics were calculated using simulated and observed time series of daily discharge for the period 1979-2018 at the location of the most downstream station with available observations.
- For graphical representation, these values are projected to the whole catchment area of the respective river.
- Trends were calculated from 1960-2014 at the same locations.
- For ICON-CLM variables, monthly mean time series for the respective upstream catchments were calculated.

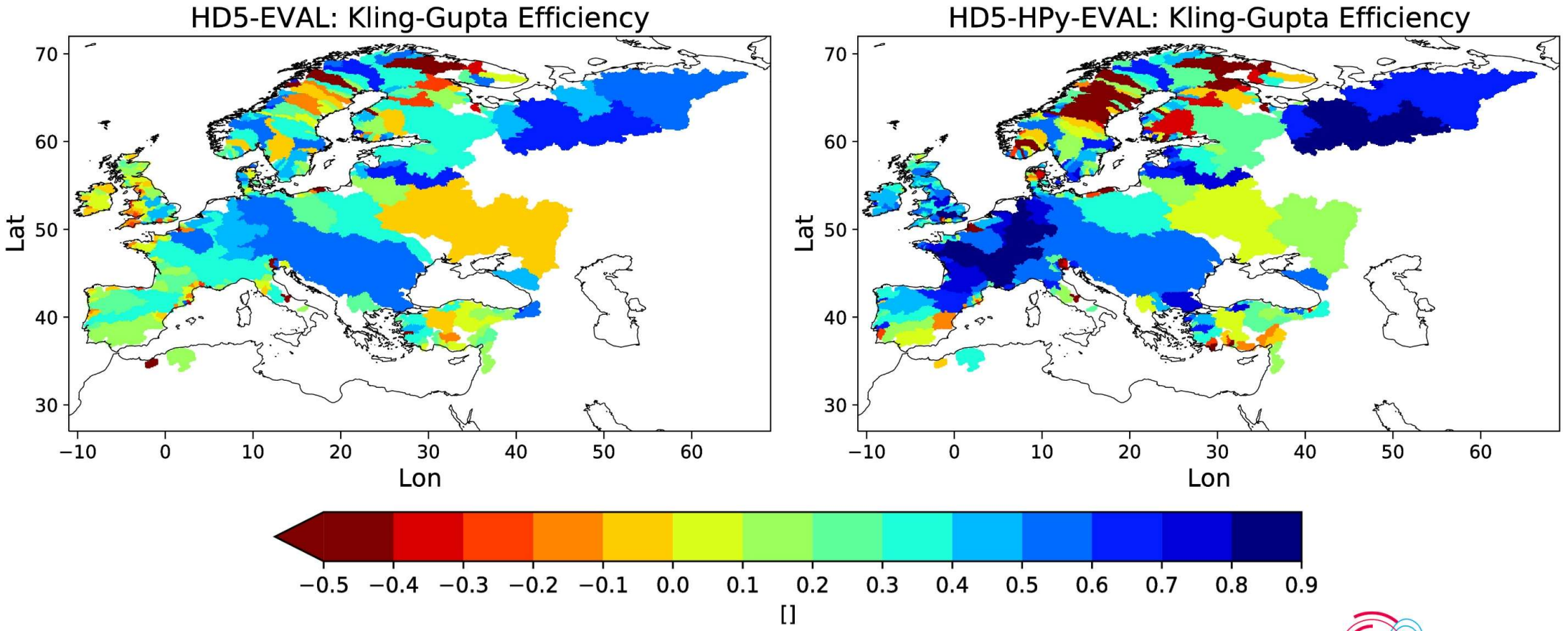
European HD model domain and 7 selected river catchments



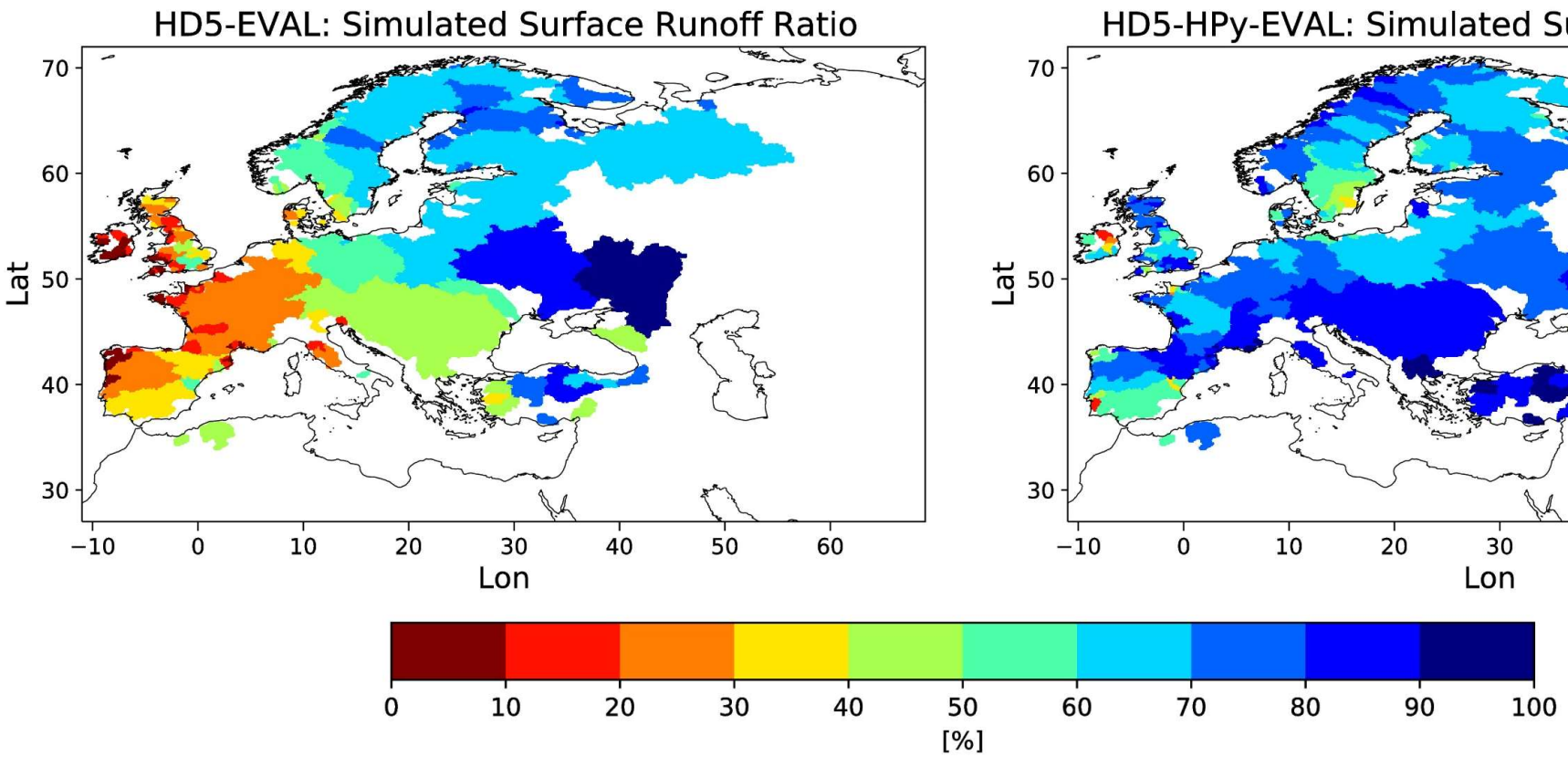
Metrics for daily discharge - Hindcast, 1979-2018



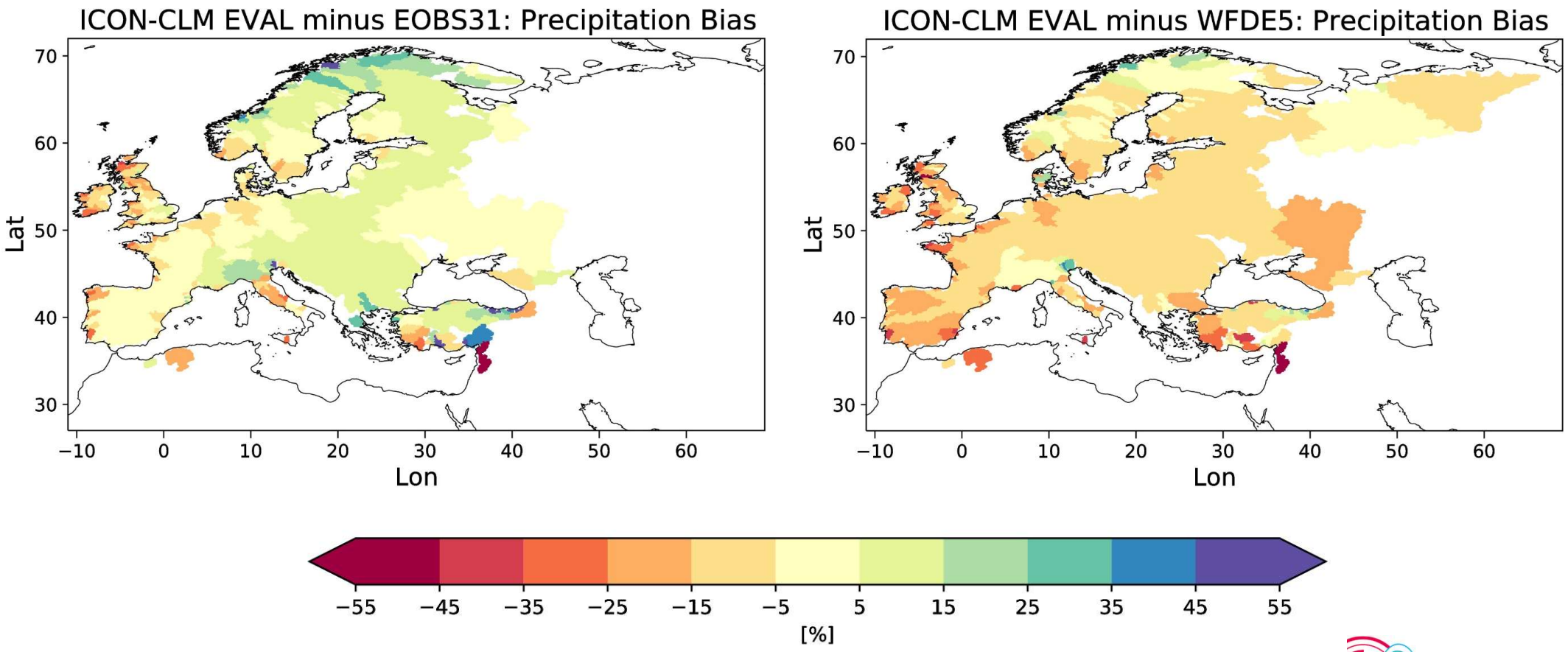
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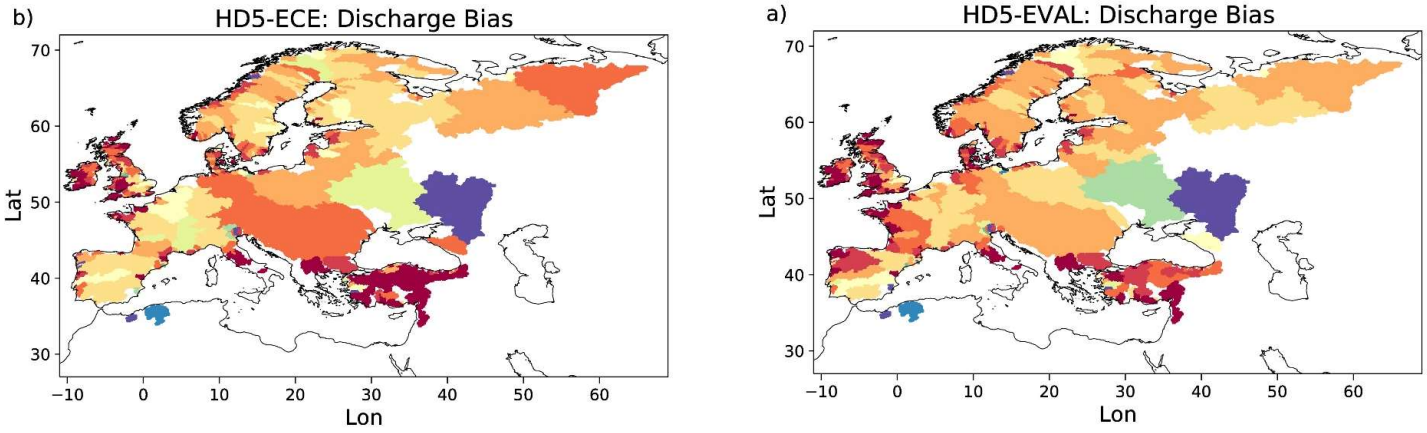
Surface runoff ratio [%; surface runoff / total runoff]

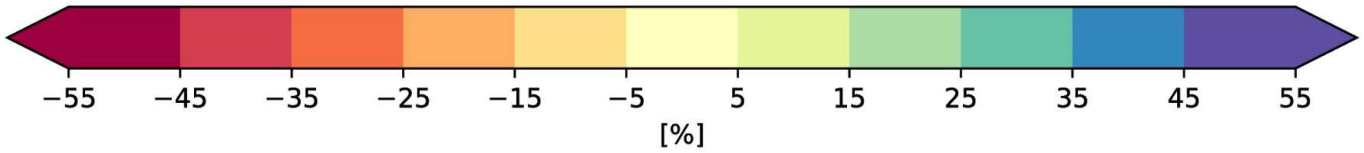


Evaluation of ICON-CLM EVAL precipitation: 1979-2018



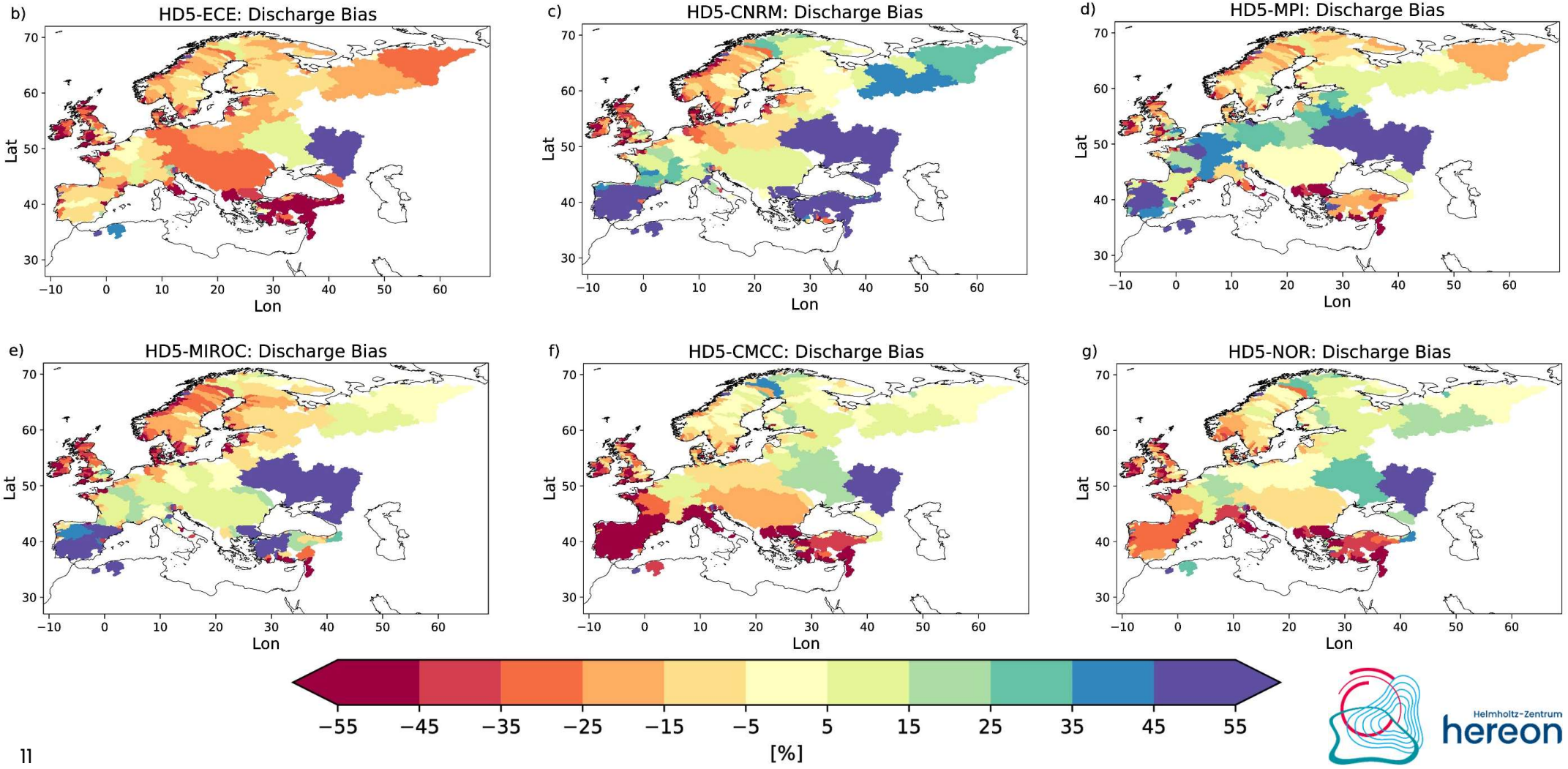
Discharge Bias - Historical, 1960-2014



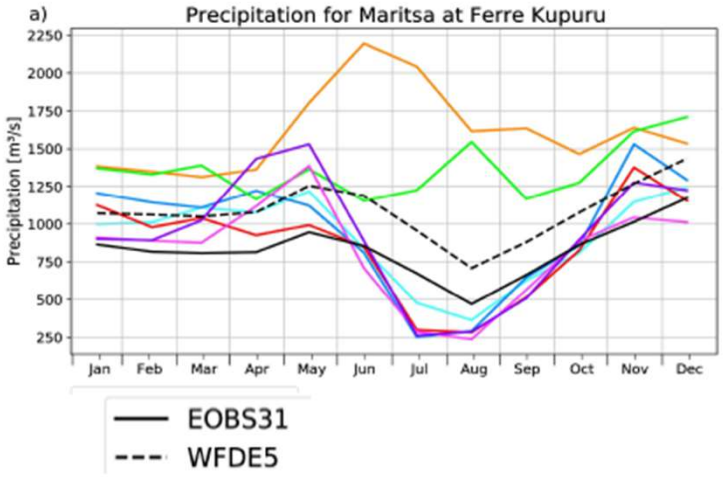


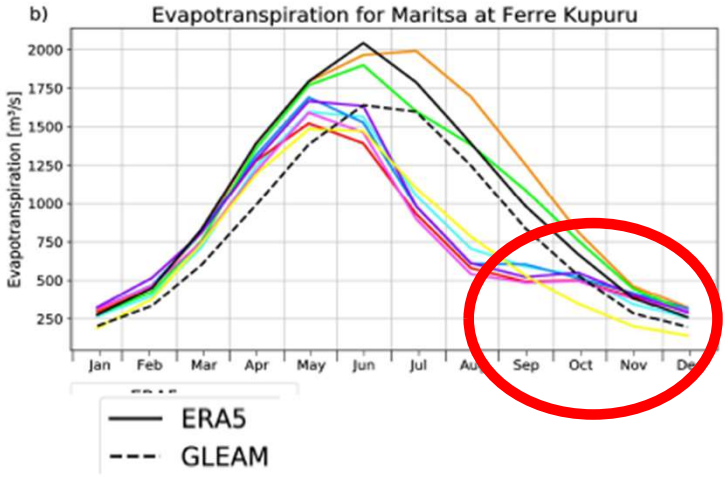
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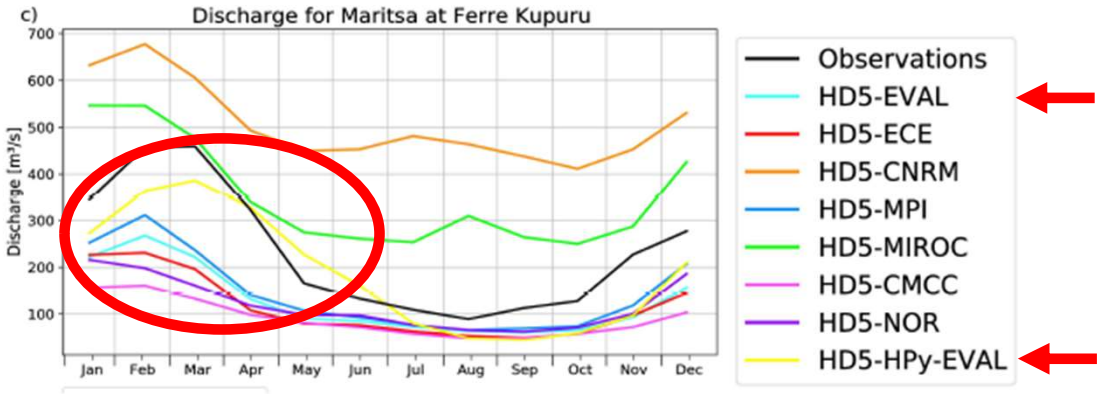
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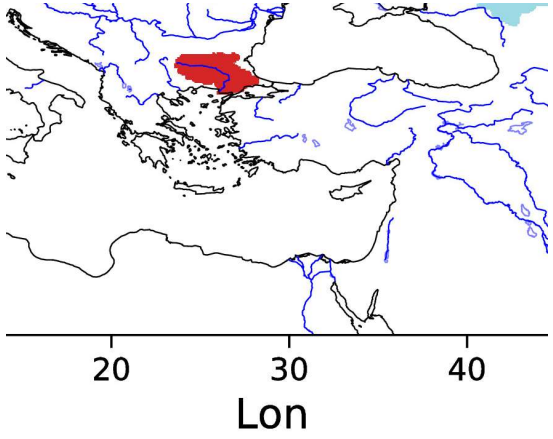


Maritsa, Monthly climatologies for 1960-2014

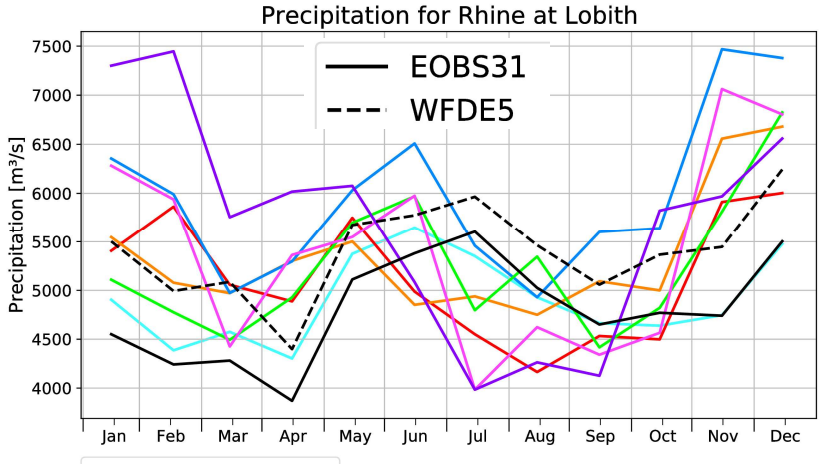


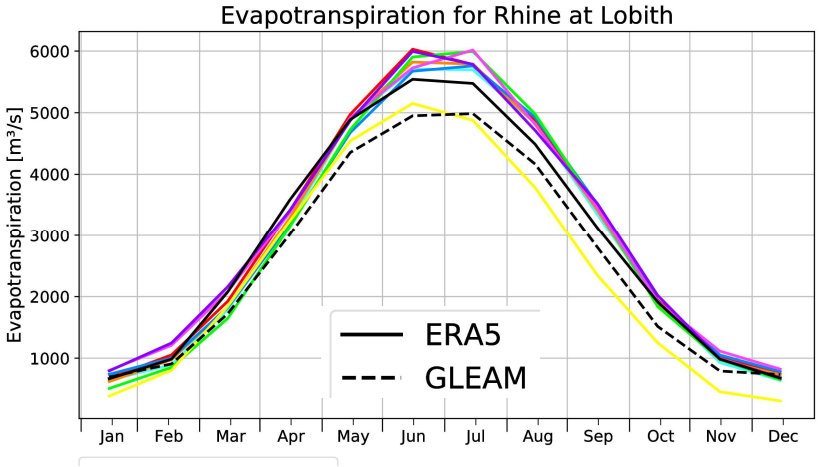


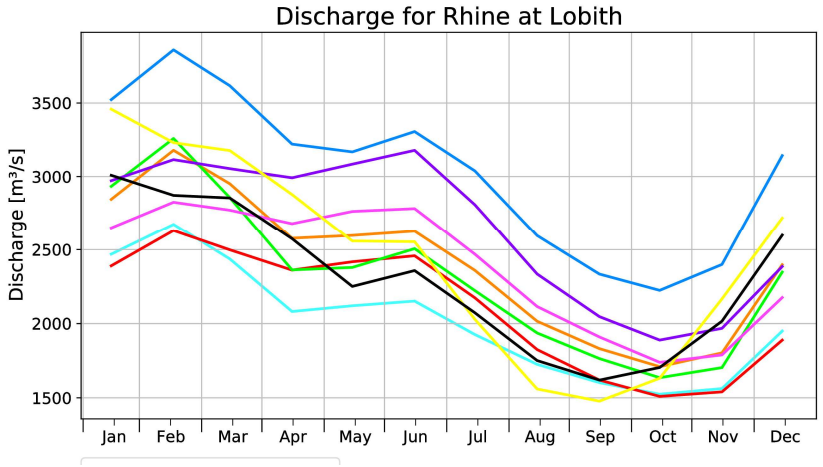


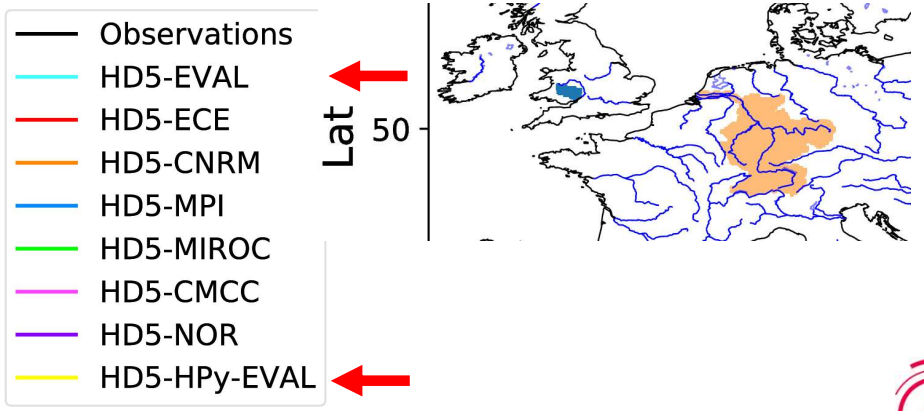


Rhine, Monthly climatologies for 1960–2014

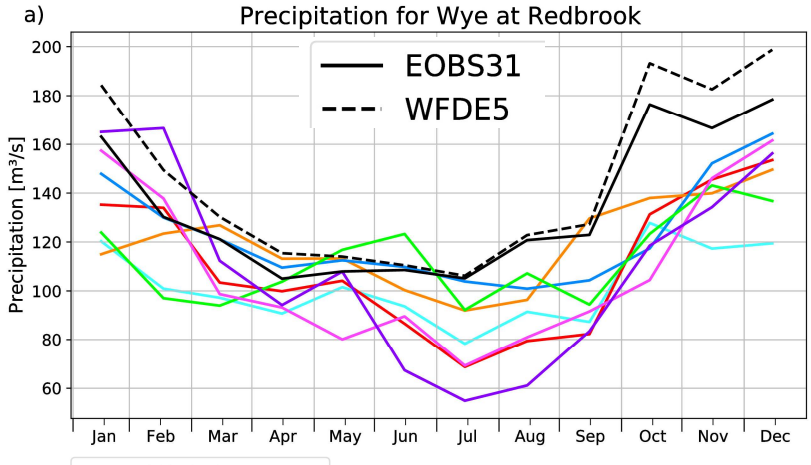


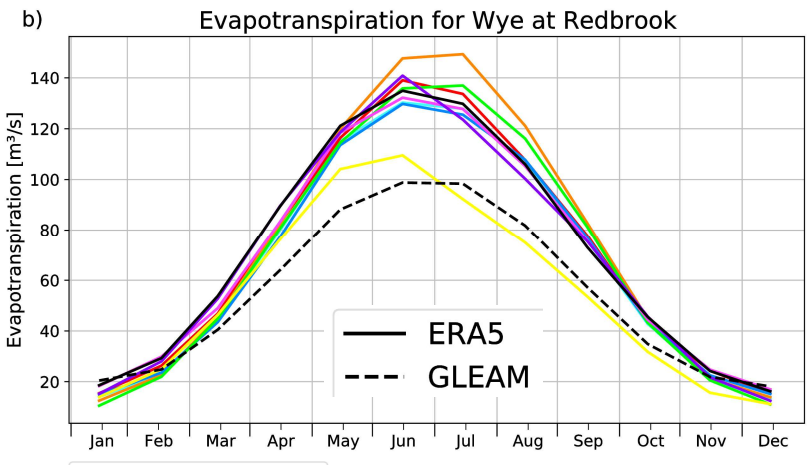


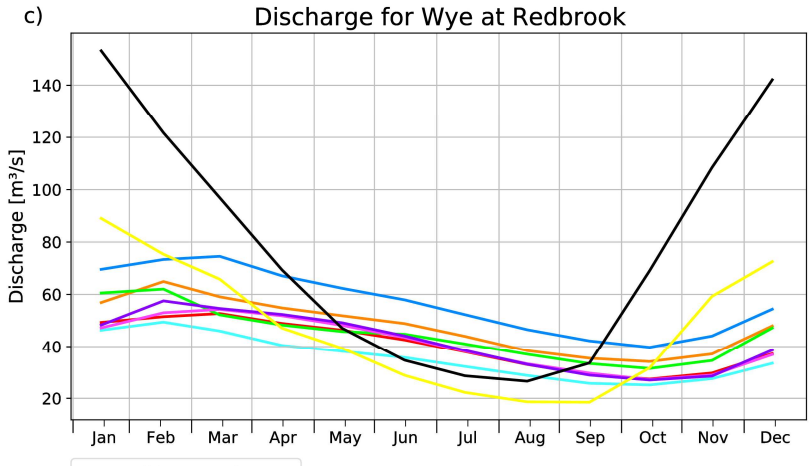


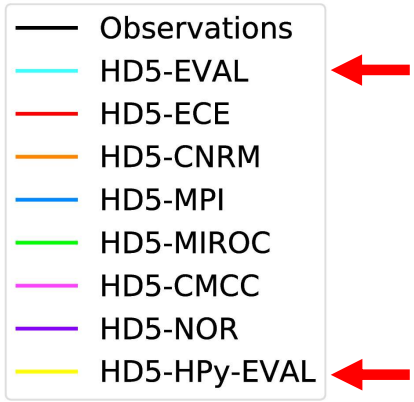


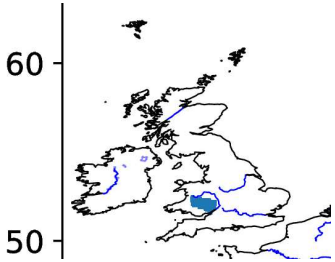
Wye, Monthly climatologies for 1960–2014



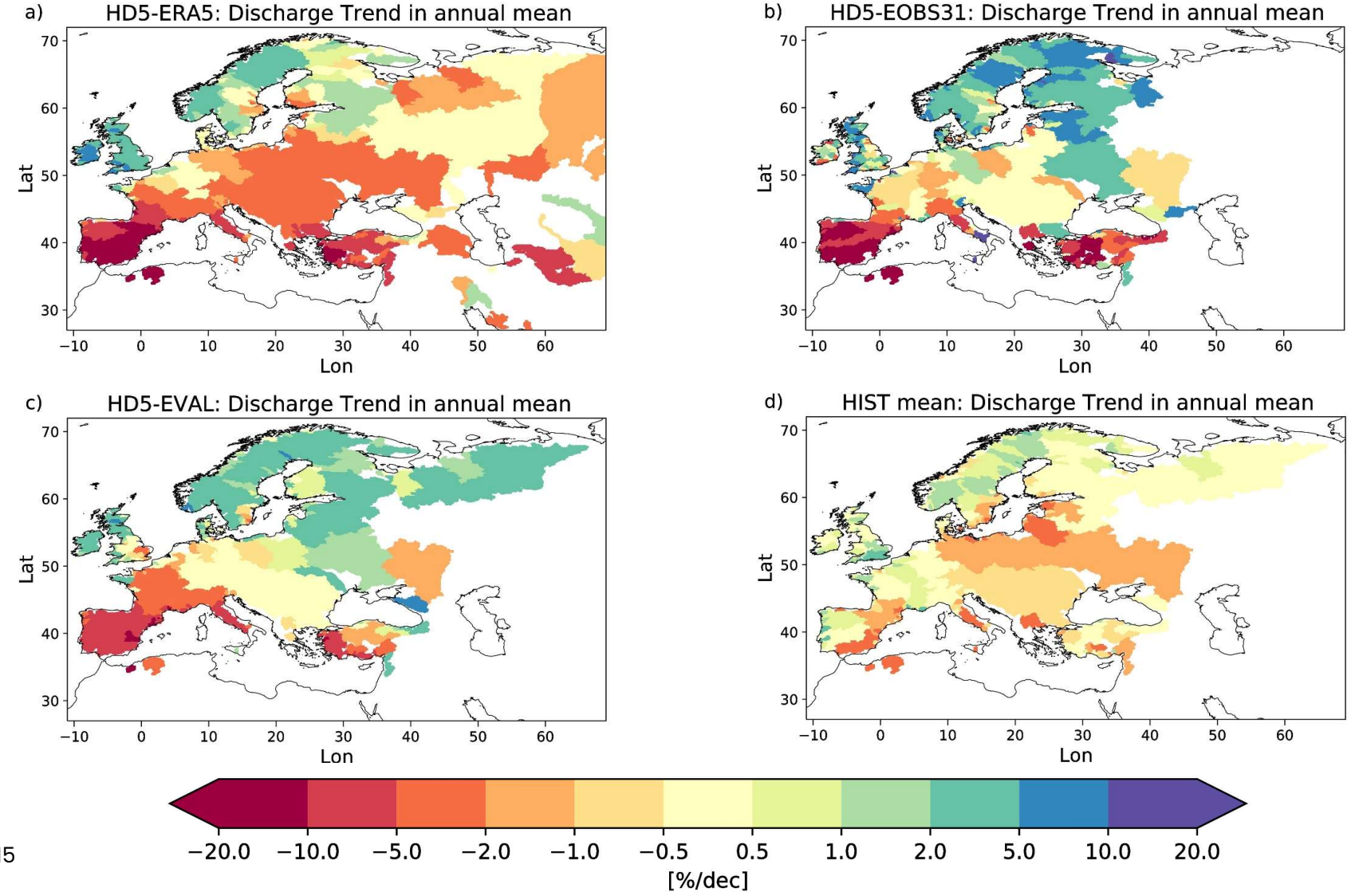






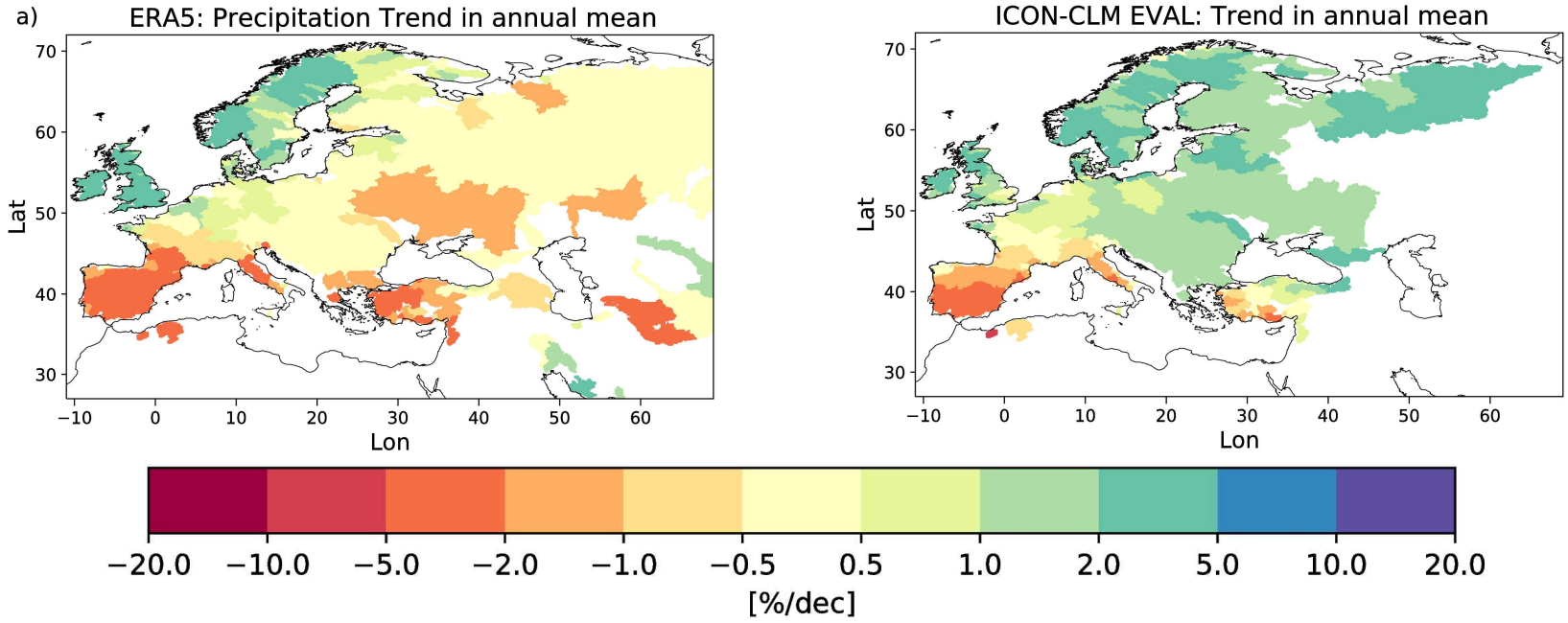


Annual mean discharge trends 1960–2014: Hindcast



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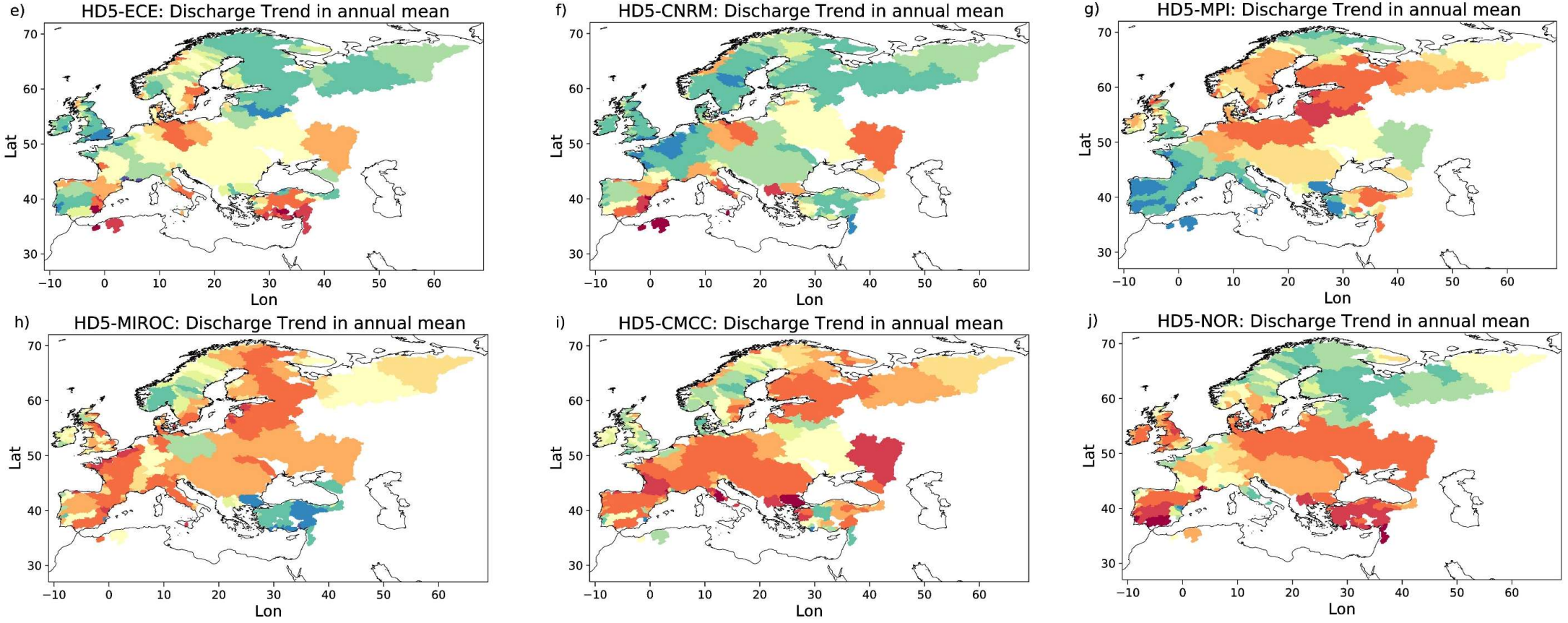
Inconsistent ERA5 driven trends imposed by precipitation



- ERA5 precipitation is likely be affected by the amount and type of data available for data assimilation during different time periods.
- Such an impact of the observing system on integrated water vapour and precipitation was also found in the ERA40 reanalysis (Bengtsson et al., 2004; Hagemann et al., 2005)

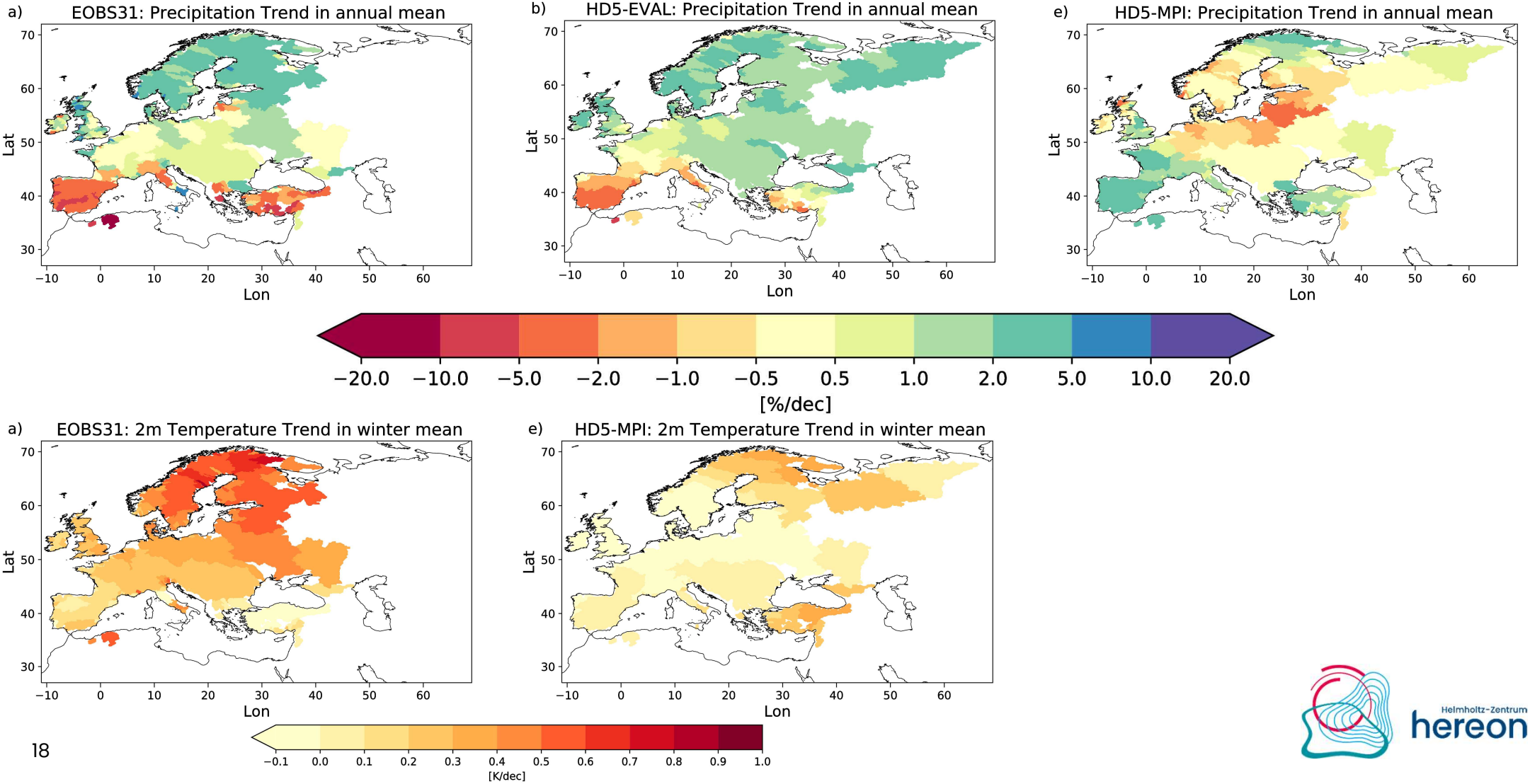
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Annual mean discharge trends 1960–2014: Historical



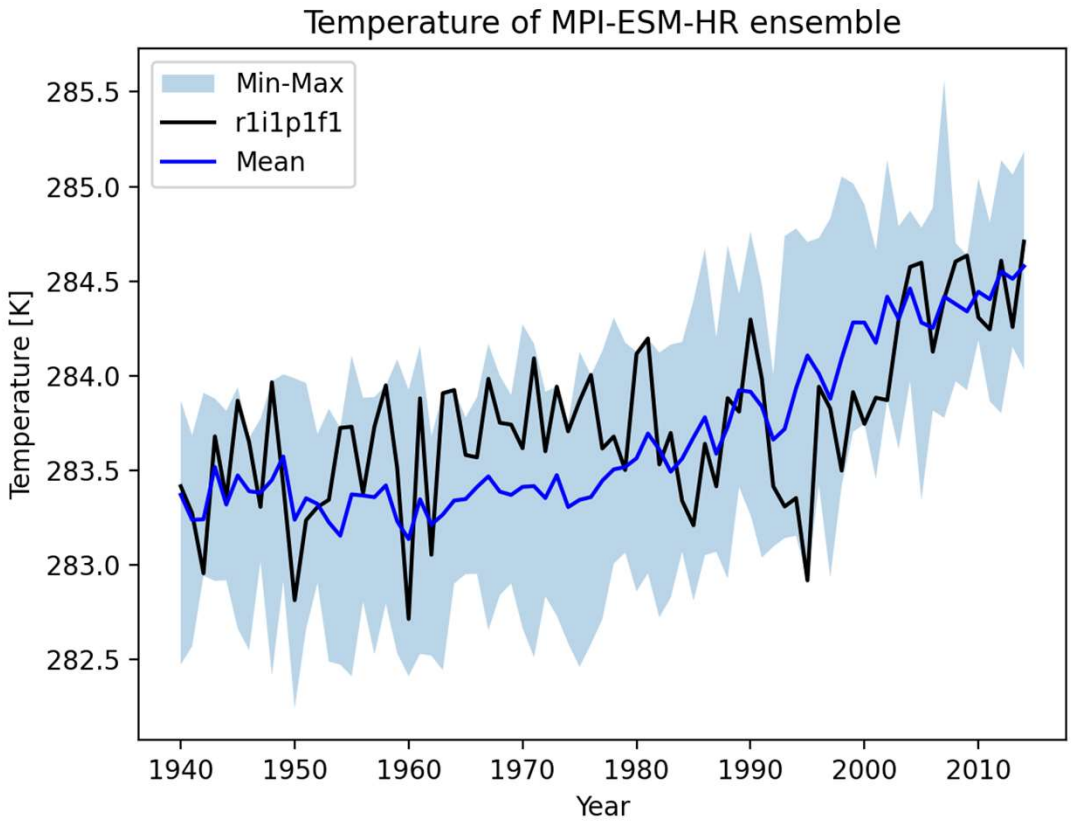
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Annual mean trends 1960-2014



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Global 2m temperature of MPI-ESM-HR ensemble



Summary 1

- ICON-CLM-based simulations show widespread dry discharge biases
- Biases are primarily caused by underestimated precipitation and an inadequately low surface runoff fraction simulated by the TERRA land surface scheme
- Reduced variability by less surface runoff is similar to the effect of human regulation so that HD5-Hpy-EVAL discharge metrics get worse over Scandinavia where many rivers are regulated.
- ICON-CLM evapotranspiration shows limited sensitivity to deficits in precipitation due to overly wet soil states (e.g. Wye, Rhine).
- Relatively high KGE values of HD5-HPy-EVAL suggest that the atmospheric forcing variables of ICON-CLM are rather well suited for hydrological impact studies.

Summary 2

- Hindcasts show robust climate change signals, such as an increase in discharge in northern Europe and a decrease in southern Europe.
- Historical simulations show inconsistent and often contradictory trend patterns that are strongly influenced by their driving GCMs.
- MPI-ESM based simulation shows unexpected behaviour, with lower mean warming, almost absent winter warming and opposite trend pattern in precipitation.
  - Selected MPI-ESM-HR ensemble member reflects the uncertainty introduced by natural variability well.
  - Difficult to communicate its results to stakeholders and the general public
- Results highlight the substantial spread caused by natural variability and GCM uncertainty in historical simulations

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Thank you for your attention!

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