LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

ClimEx
www.climex-project.org

ARSINOE

The International Commission for the Hydrology of the Rhine basin
CHR Symposium in Olten, Switzerland
02 June 2022

Assessing the impacts of climate change and climate variability on hydro-meteorological extreme events - results and lessons learned from the ClimEx-projects in the Upper Danube and Main river basins

Raul Wood & Ralf Ludwig
Physical Geography and Environmental Modeling
Department of Geography
Faculty of Geosciences
Ludwig-Maximilians-Universität München (LMU)
raul.wood@lmu.de

Climate change and hydrological extreme events

Phase 1: Risks and Perspectives for water resources management in Bavaria (and Québec)

Phase 2: Climate and Land Use Change: Interactions and implications for low flows, dryness and drought

www.climex-project.org

gefördert durch
Bayerisches Staatsministerium für
Umwelt und Verbraucherschutz

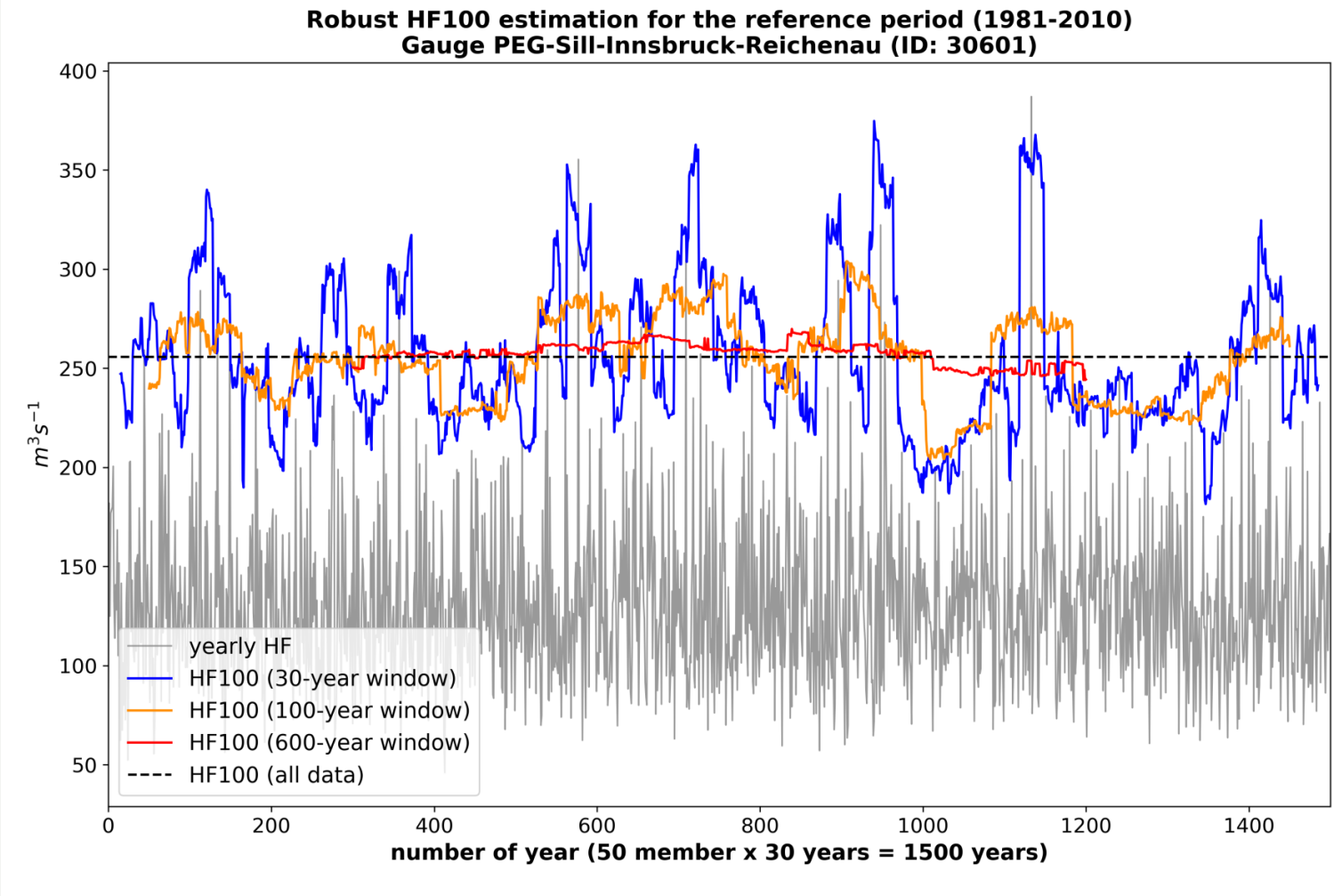
The ClimEx-Project – Research questions

- Does climate change contribute to higher intensities and frequencies of hydro-meteorological extreme events? If yes, how?
- How can we distinguish between the effects of natural variability and a “clear” climate change signal?
- Which other impacts must be expected for Bavaria (and Québec) under the assumption of a high-GHG scenario (RCP8.5)?

Major flood events in Québec
1996/2011/2017/2019

Major flood events in Bavaria
1999/2002/2005/2013/2016

The issue with low-likelihood events – Sample Size



Statistical Problem

extrapolation from a limited sample size

+

Natural Climate Variability

interannual – decadal hydrometeorological variability

Solution:

➔ increase in sample size

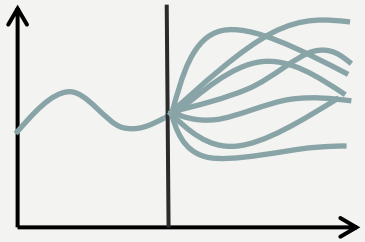
by

Single Model Initial condition Large Ensembles (SMILE)

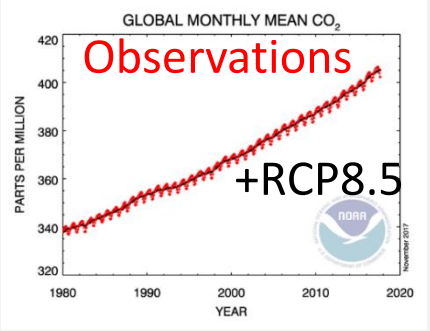
The ClimEx-Project – Methodology

Seeking answers with a SMILE

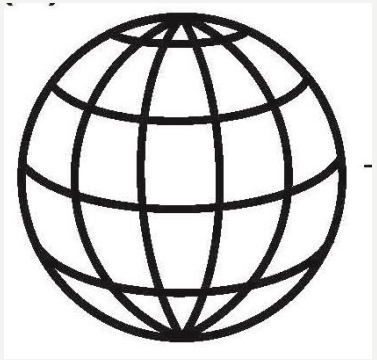
Initial conditions



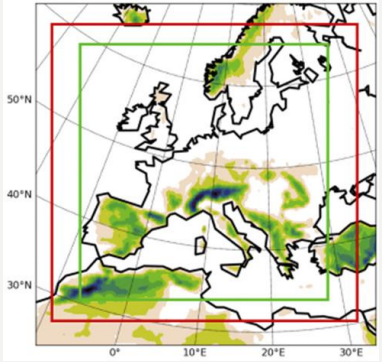
GHG emissions



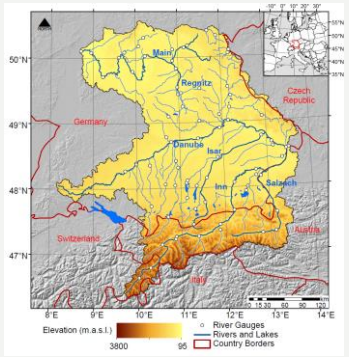
GCM:
CanESM2-LE
(Kirchmeier-Young 2017)



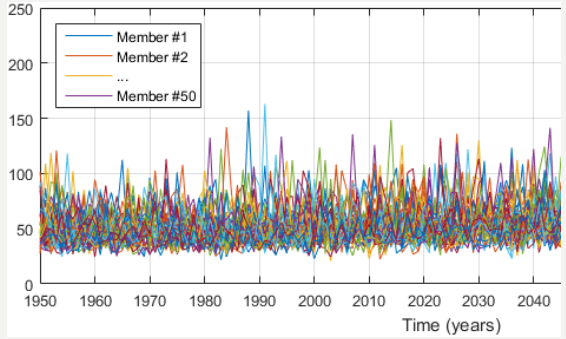
RCM:
CRCM5-LE*
(Leduc 2019)



Hydrology:
WaSiM*
(Willkofer 2020)



Streamflow

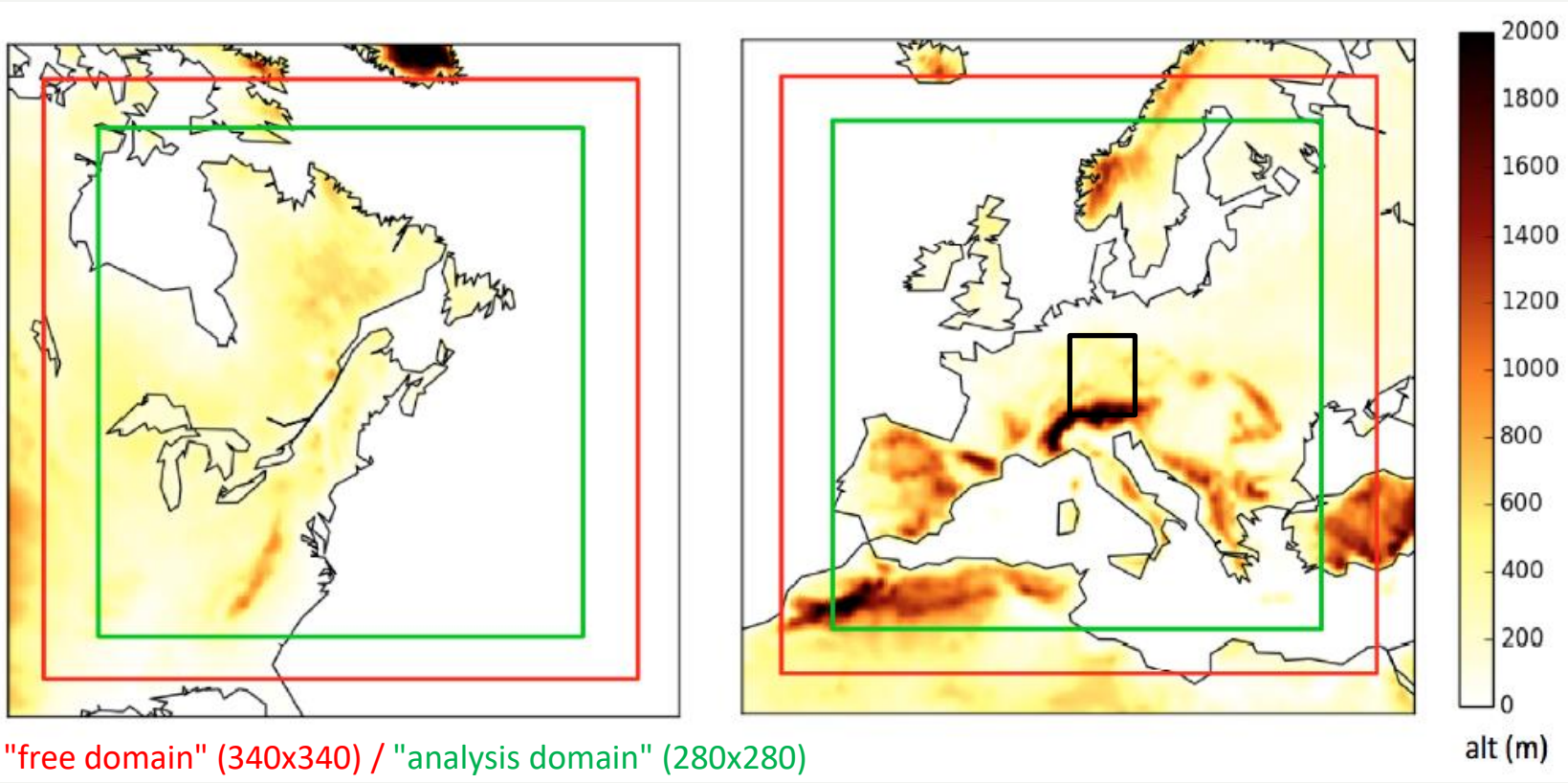


50 member x 150 years = 7500 years

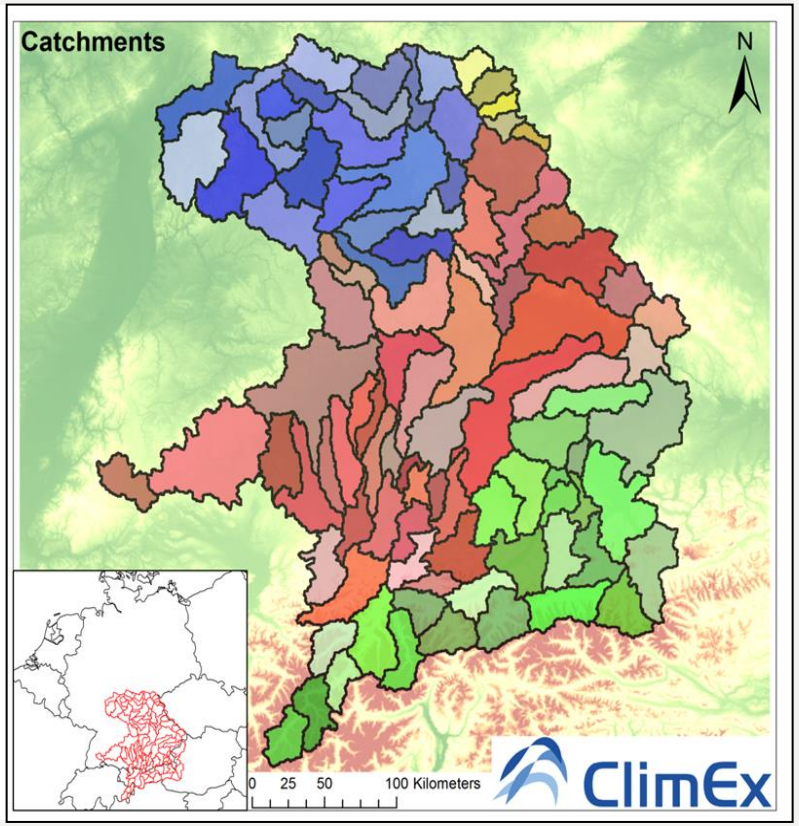
Historic + Future streamflow

* Simulations with the CRCM5 and WaSiM were performed within the ClimEx project funded by the Bavarian Ministry for the Environment and Consumer Protection

The ClimEx-Project – Case studies



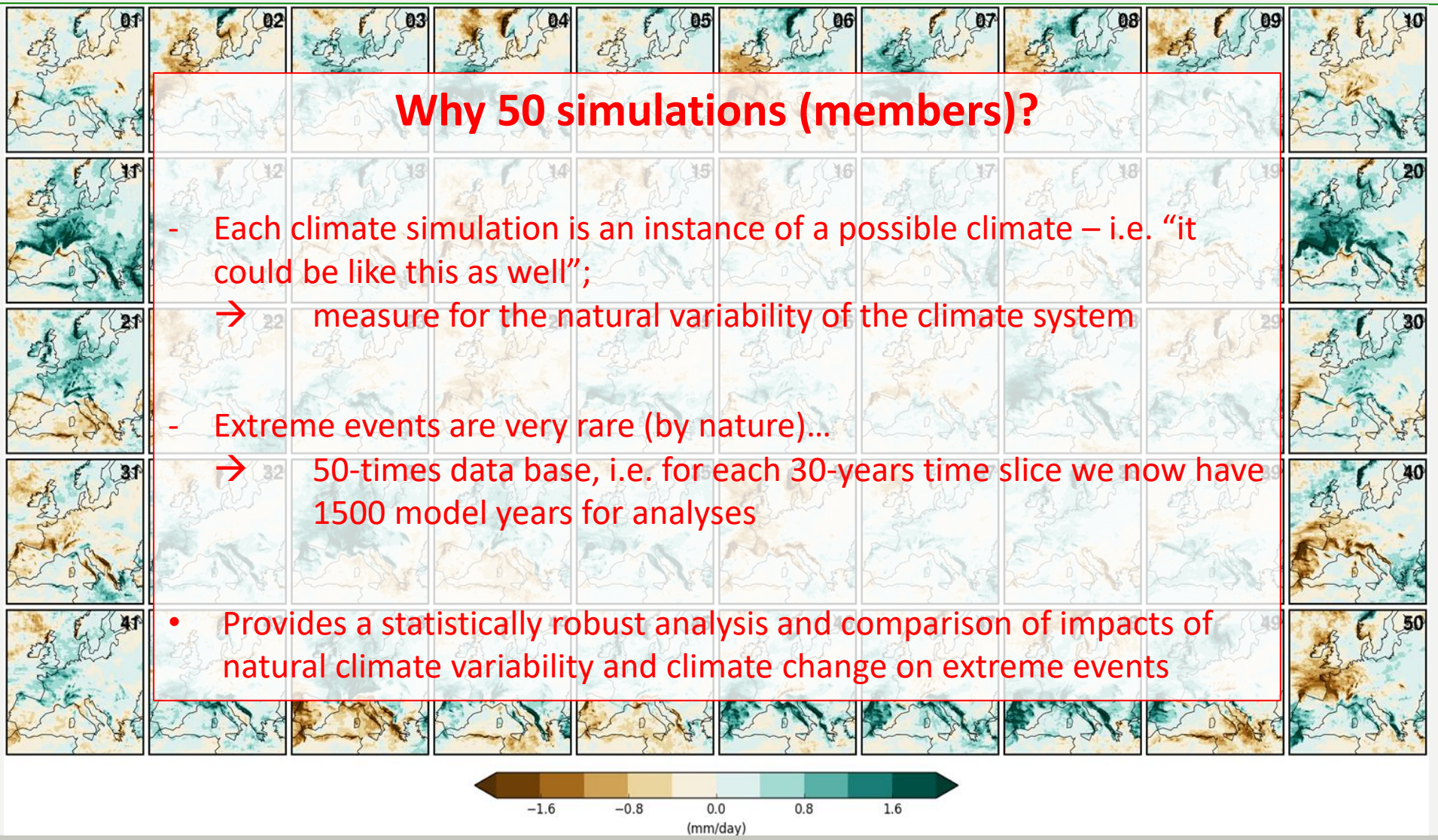
"free domain" (340x340) / "analysis domain" (280x280)



Scope: Assess the climate change related flood risk for 98 river basins in (hydrological) Bavaria (~100.000km²)

Goal: a) Improve process understanding of non-linear hydro-meteorological extreme events
b) Provide management options for stakeholders and decision makers to reduce related risks

Results – Natural variability (of precipitation)



Why 50 simulations (members)?

- Each climate simulation is an instance of a possible climate – i.e. “it could be like this as well”;
  → measure for the natural variability of the climate system

- Extreme events are very rare (by nature)…
  → 50-times data base, i.e. for each 30-years time slice we now have 1500 model years for analyses

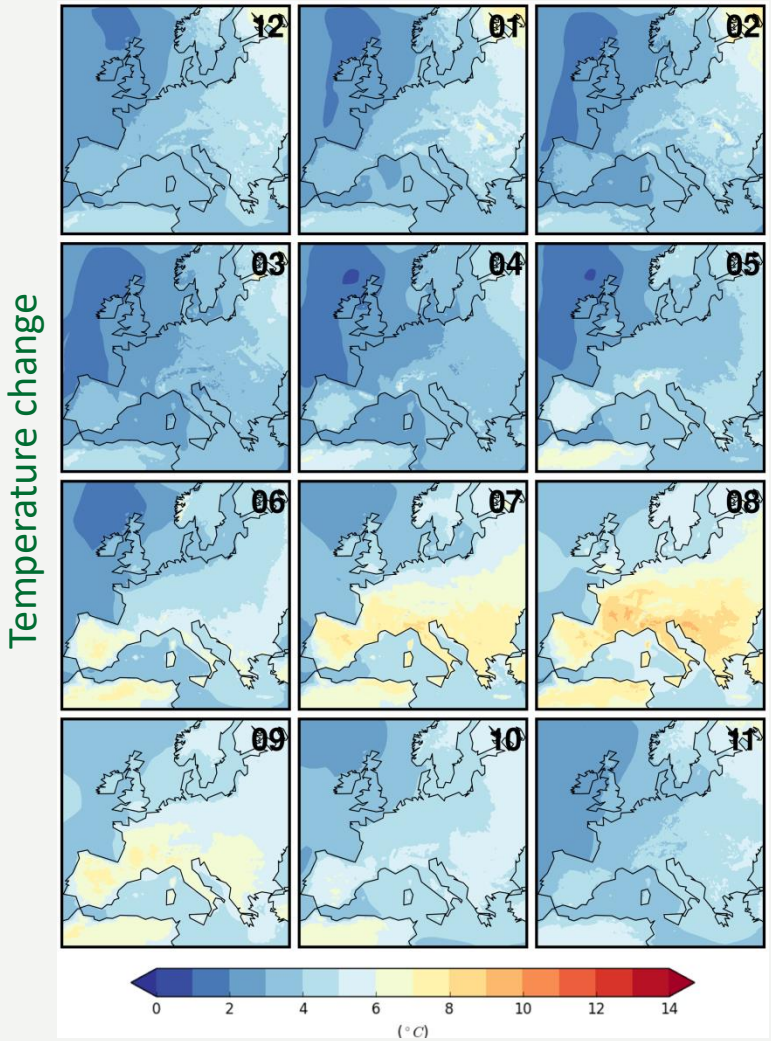
- Provides a statistically robust analysis and comparison of impacts of natural climate variability and climate change on extreme events

50 possible future changes for PRC (in %) between 2020-2039 and 2000-2019 over Europe from CanESM2-CRCM5 at a 12-km resolution

(Leduc et al., 2019, *JAMC*)

Results - Temperature and Precipitation in Europe

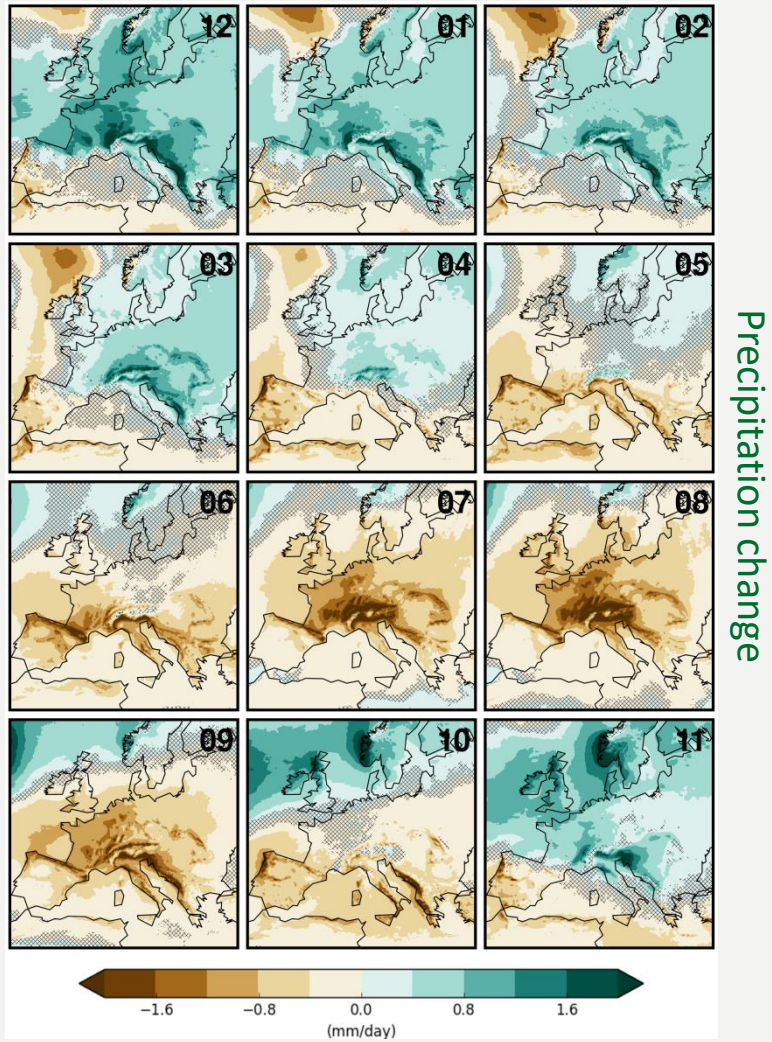
Monthly change of temperature (left) and precipitation (right) (2080-2099 vs. 2000-2019)



Temperature increase in all months, especially in summer

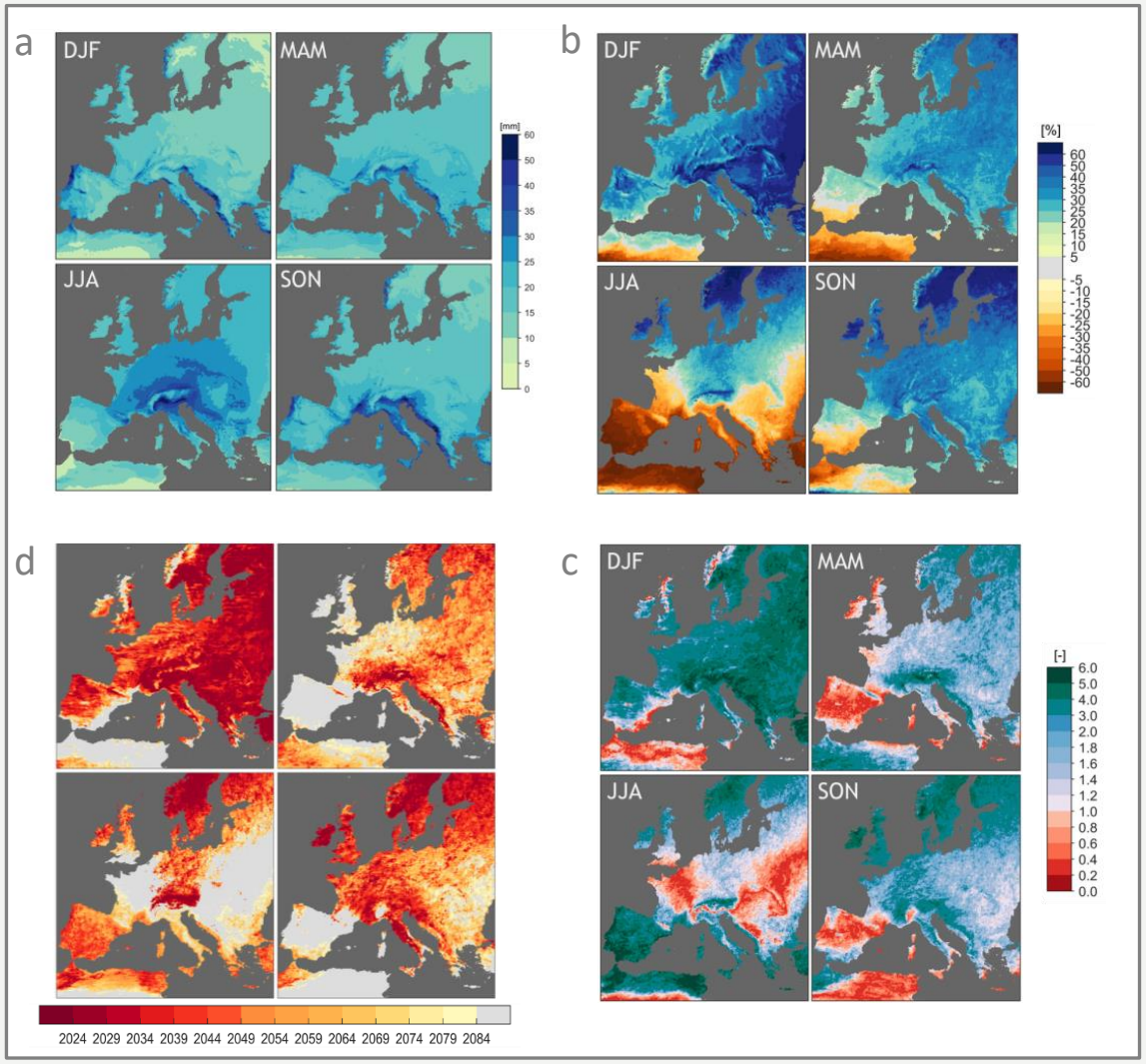
Strong precipitation **increase** in **winter** months (Nov-Mar)

Strong precipitation **decline** in **summer** months (Jun-Sep)



(Leduc et al., 2019, *JAMC*)

Results – Heavy precipitation (Rx3h)



Maximum 3h-precipitation (Rx3h)

a) seasonal distribution of Rx3h over Europe (reference period 1980-2009)

b) Climate change signal (%) (future 2070-2099)

c) Strong geographical differences in signal/noise ratio (2070-2099)

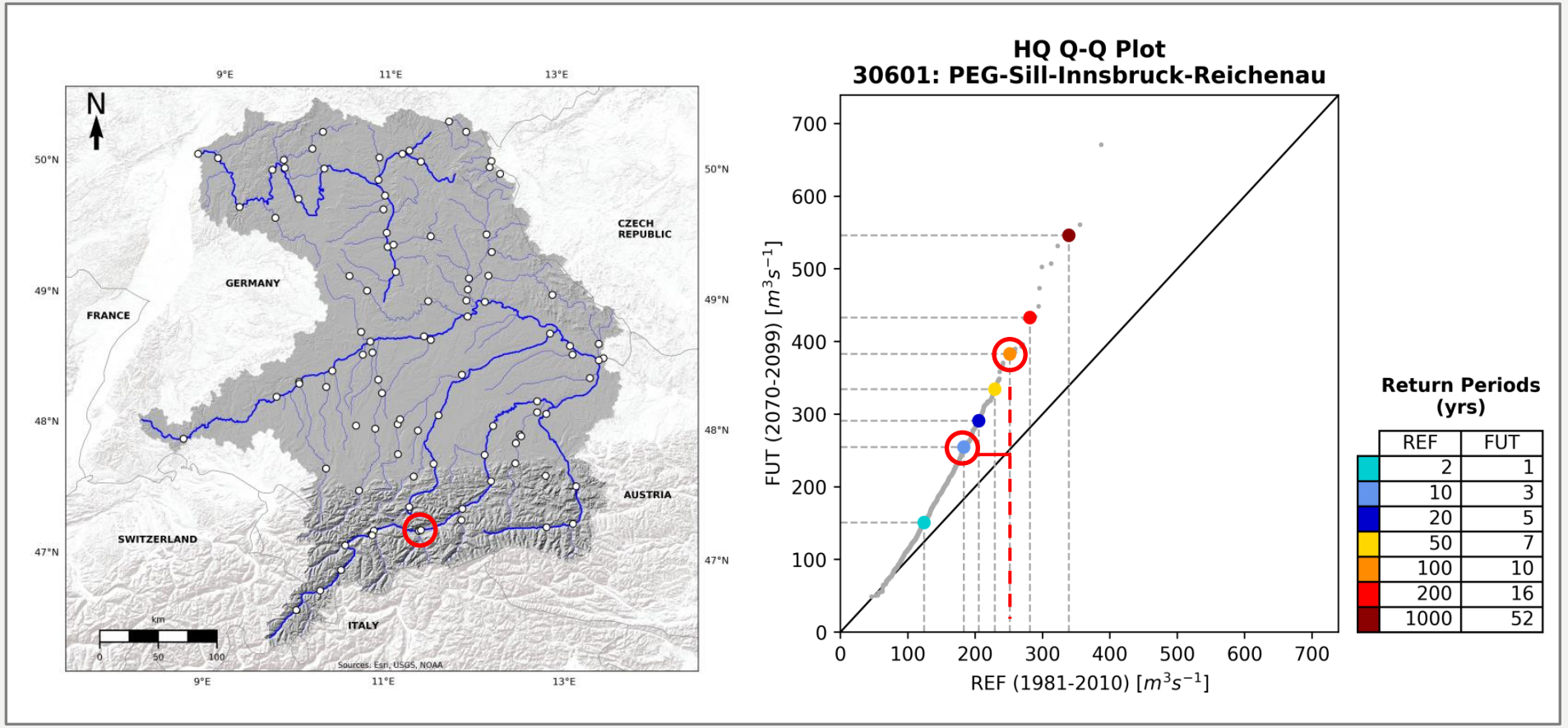
d) Calculation of time of emergence (with S/N > 1)

(Wood & Ludwig, 2020, *GRL*)

Hydrometeorological Extremes (in Bavaria)

- Floods -

Results – Will extreme flows/floods (e.g. HQ100) be more severe?



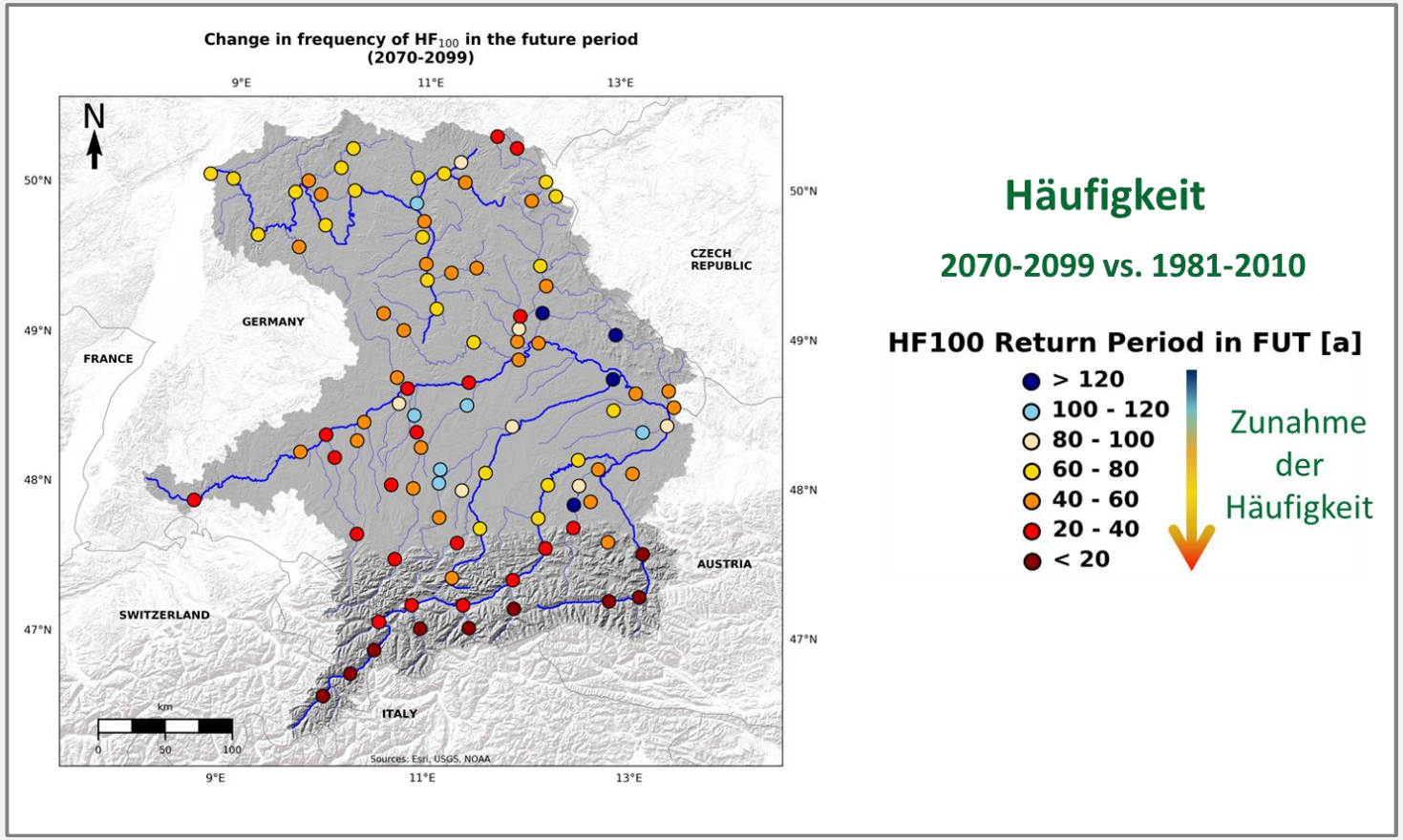
Intensity: HQ100 in the reference period: 250 m³/s; in the far future: 390 m³/s

Frequency: HQ100 in reference period will be a HQ10 in the far future!

(Willkofer, Wood, et al., in prep.)

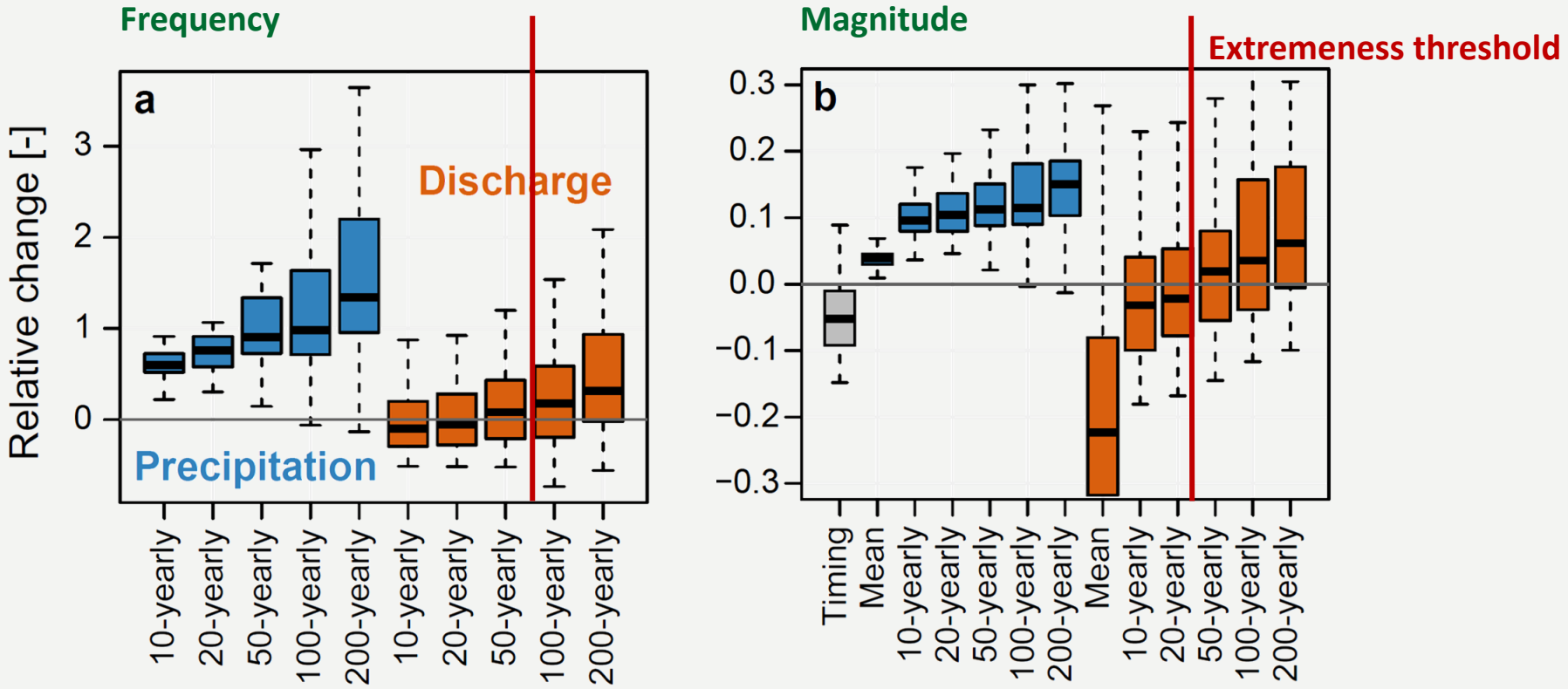
Results – Will extreme flows/floods (e.g. HQ100) be more severe?

Changes in Frequency and Intensity of HQ100 in Bavarian river basins



(Willkofer, Wood, et al., in prep.)

Results – Non-linearity in changing flood extremes



Threshold behavior in flood response to extreme precipitation: above threshold response is dominated by precipitation, below modulated by land-surface processes

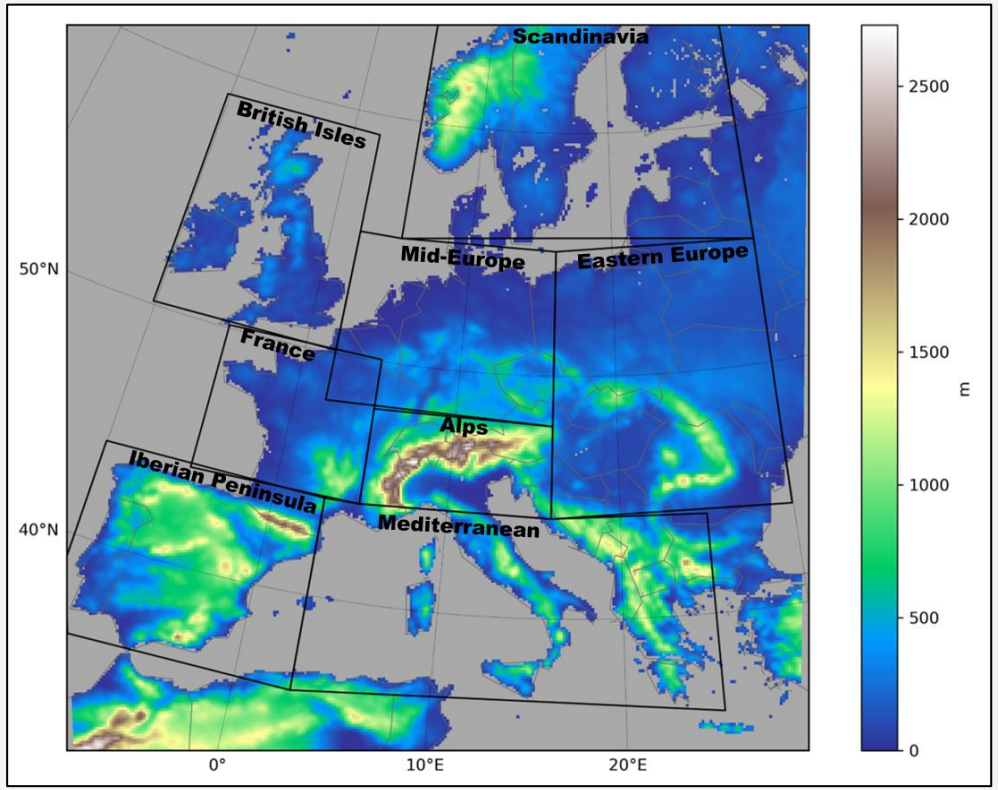
(Brunner, Swain, Wood, et al., 2021, Communications Earth & Environment)

Hydrometeorological Extremes (in Europe and Bavaria)

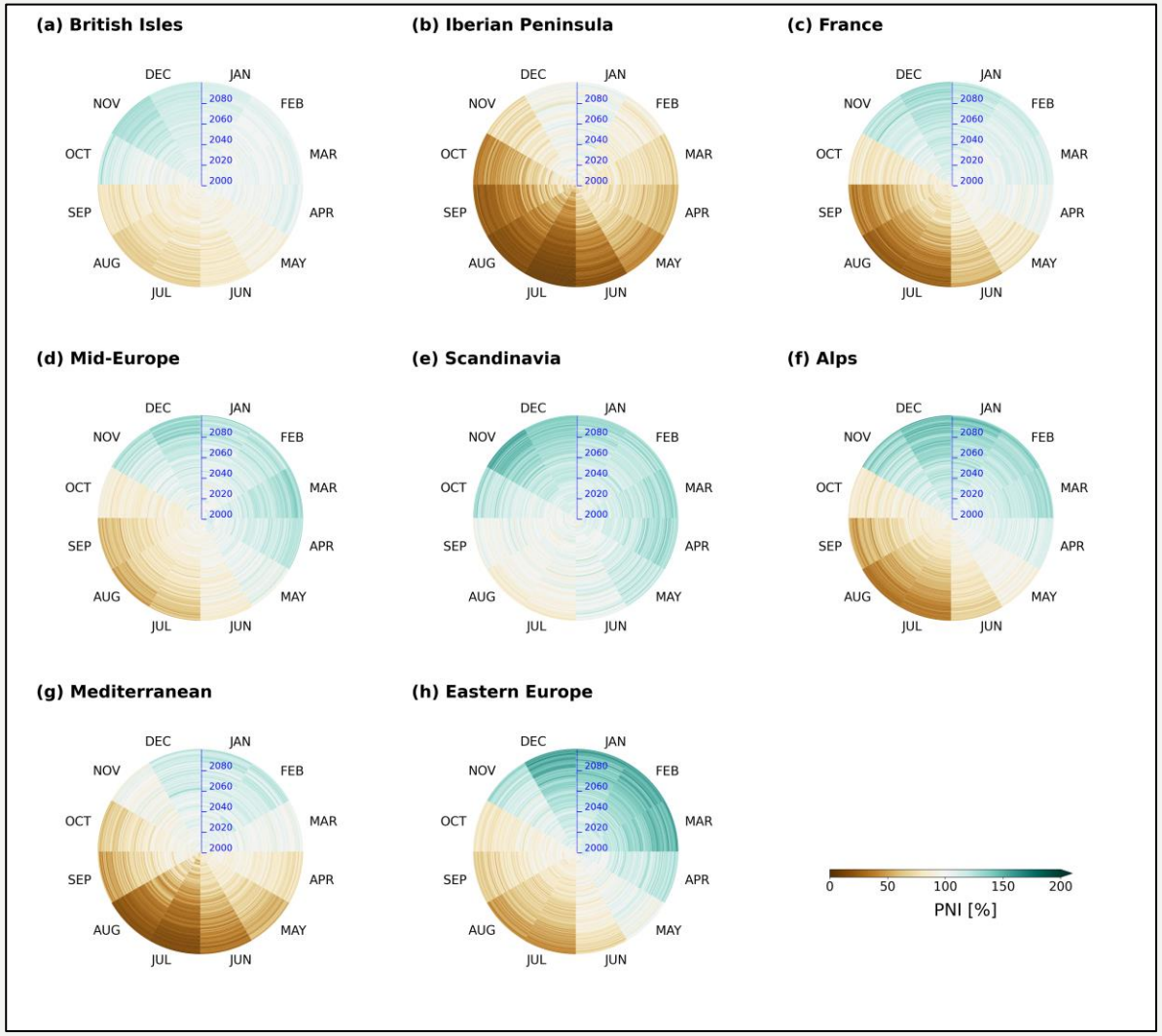
- Droughts -

Results – Dryness and Drought

Percent of Normal Index (PNI) for European regions

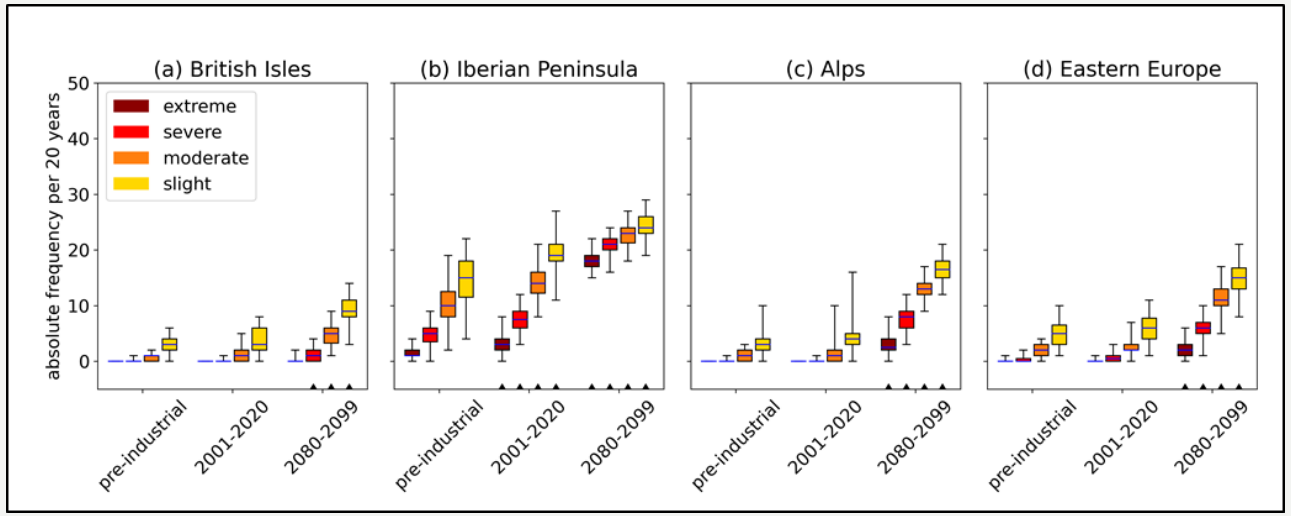


(Böhnisch, Mittermeier, Leduc & Ludwig, 2021, *Frontiers in Water*)



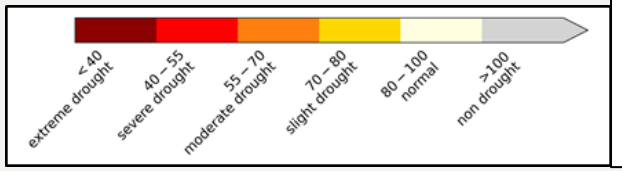
Results – Dryness and Drought

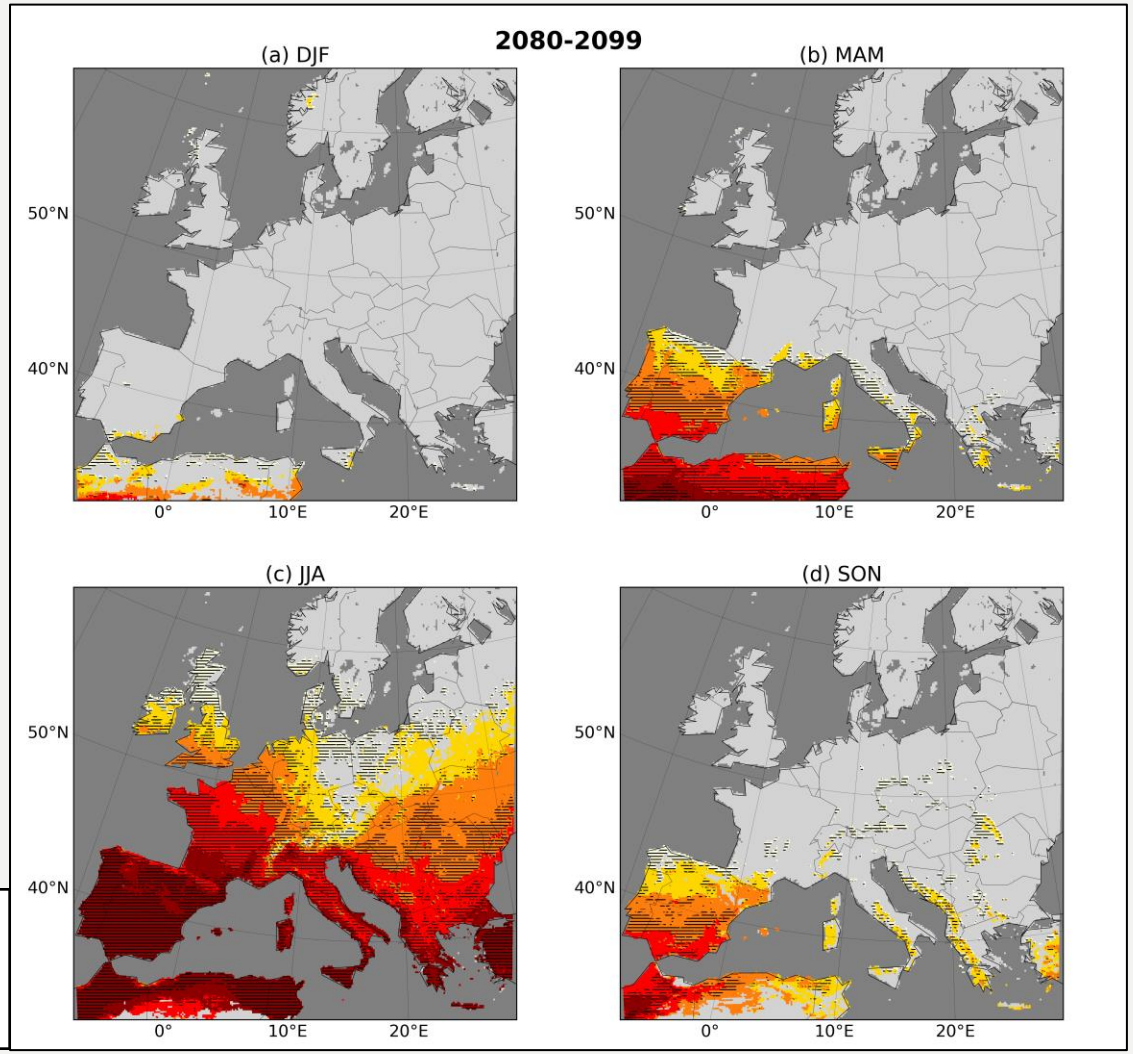
Percent of Normal Index (PNI) for European regions



Frequency of drought events in selected European regions

Increase of (extreme) drought risk in the Mediterannean, but also in Alps and Central Europe





(Böhnisch, Mittermeier, Leduc & Ludwig, 2021, *Frontiers in Water*)

Outlook for two ongoing LMU projects

ClimEx-phase 2

(funded by the Bavarian Ministry for the Environment and Consumer Protection)

&

ARSINOE

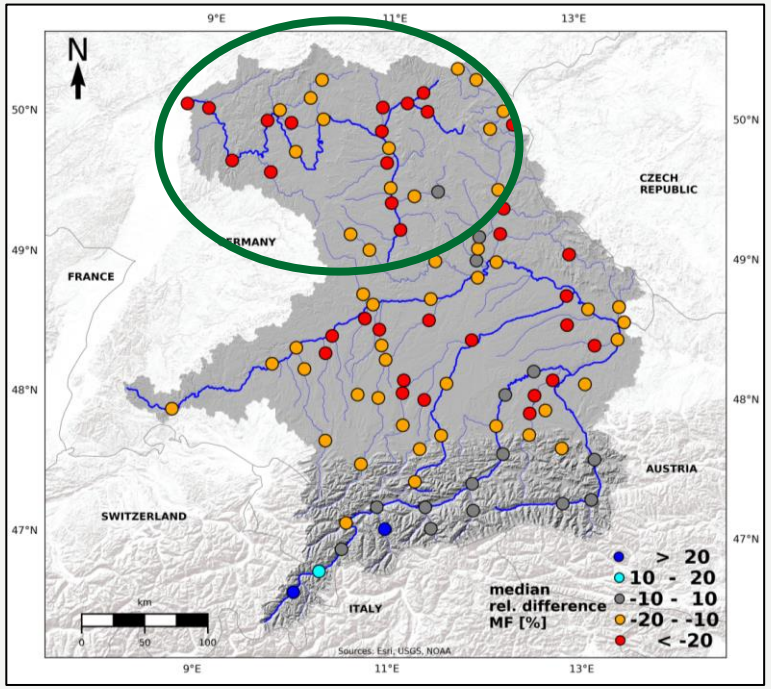
(Horizon Europe project)

Challenges for water security and water resources management

- e.g. the Main river basin -

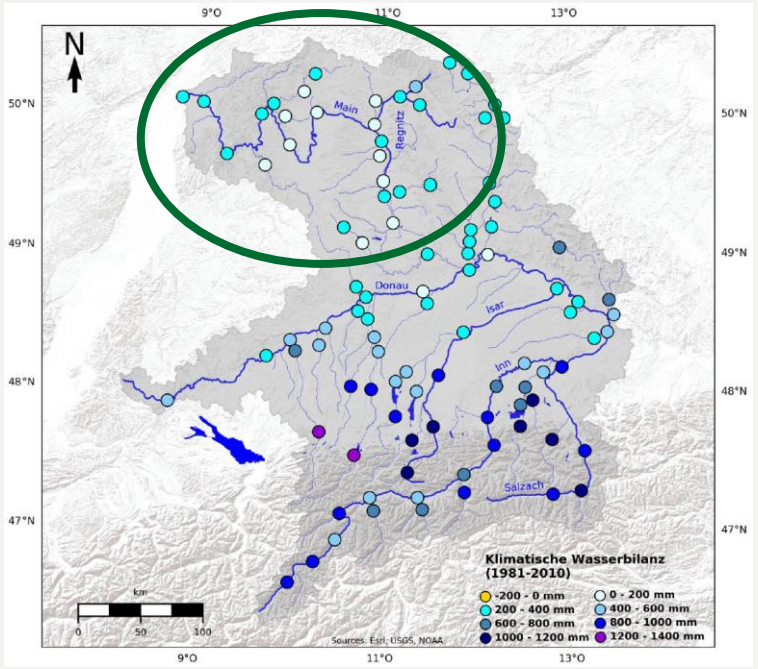
Results – Changes in annual mean flow (MQ)

Change in annual mean runoff (MQ)

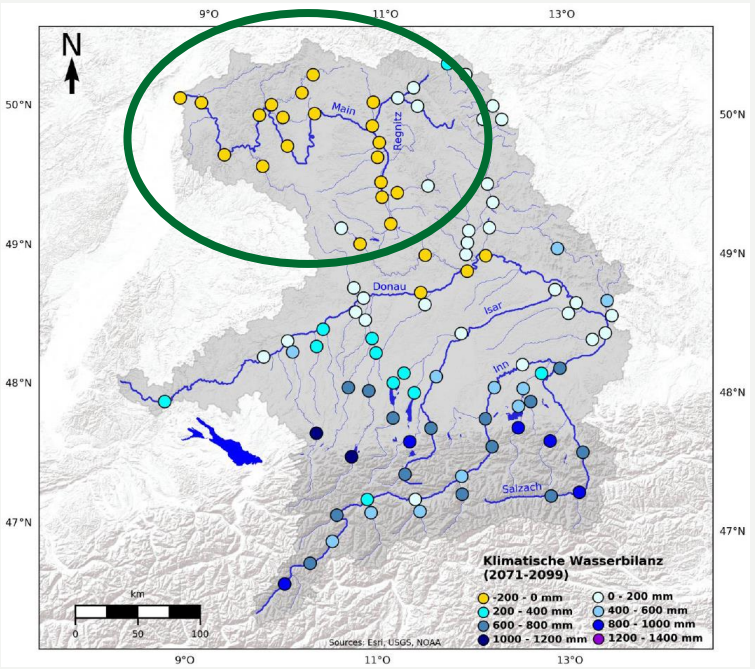


Change in climatic water balance

present

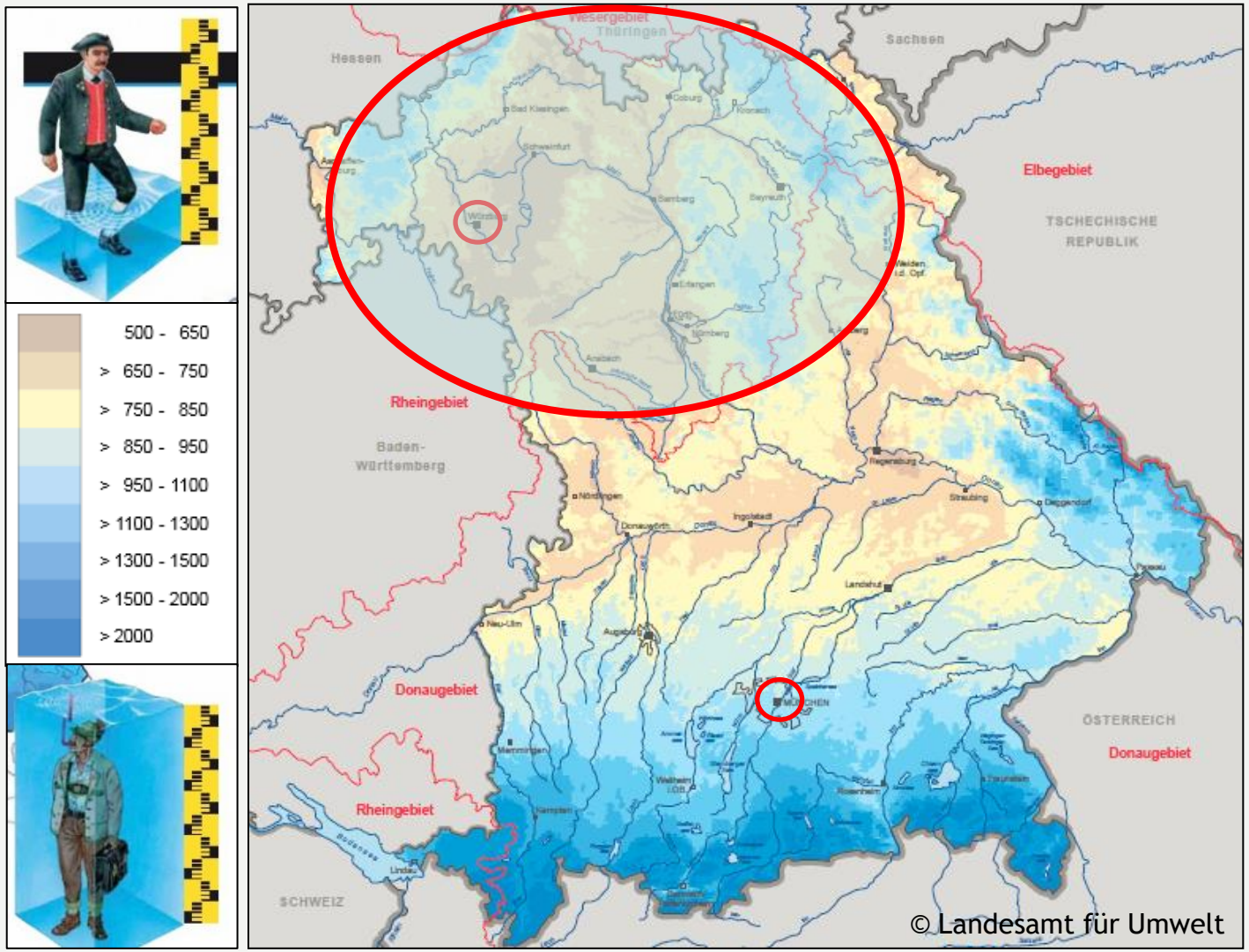


far future



A shift to drier conditions in the Main catchment

Challenges for water resources management in Bavaria



- Already water scarcity and competition
- CC causes more intense winter floods and very intense and frequent summer droughts
- Land use change and conflicts; urbanization, (irrigation) agriculture, energy transition
- Increased risks for:
  - river, reservoir, ground-water quality & quantity
  - maintaining ecosystem services
  - city utility operations (drinking water, energy/waste management, harbors)

Challenges for water resources management in Bavaria

RATIONALE

- Region is at risk for being pushed beyond its resilience threshold and will need a new level of responsiveness to cope with climate change

BARRIERS

- Limited awareness on severity of regional climate change impacts
- Science-society-policy interface operates below capacity; CC related innovations and methodologies propagate too slow into practice

OPEN ISSUES

- Counteract flood risk: New flood protection measures? Structural vs. non-structural?
- Counteract drought risk: New or extended reservoirs? Where?
- Drinking water supply: New long distance pipelines? Where can we transfer water?
- Change the demand side: Adapt land use to less water intense agriculture?

The International Commission for the Hydrology of the Rhine basin
CHR Symposium in Olten, Switzerland
02 June 2022

Assessing the impacts of climate change and climate variability on hydro-meteorological extreme events - results and lessons learned from the ClimEx-projects in the Upper Danube and Main river basins

Raul Wood & Ralf Ludwig
Physical Geography and Environm
Department of Geography
Faculty of Geosciences
Ludwig-Maximilians-Universitaet
raul.wood@lmu.de

We openly share climate simulation data with the science community
www.climex-project.org

In case of questions regarding projects and data, please contact us
raul.wood@lmu.de
r.ludwig@lmu.de