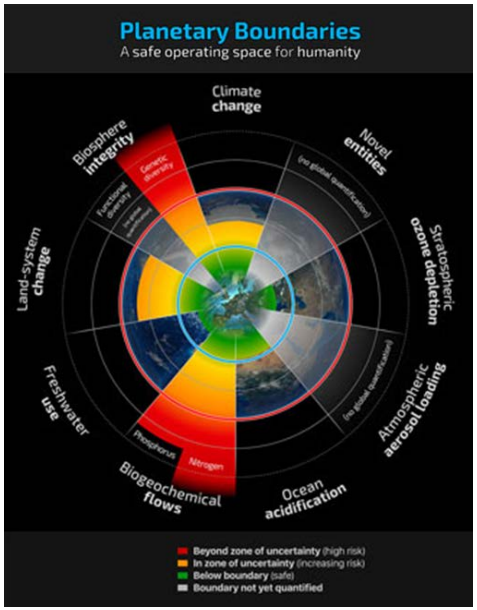
Climate Change and Energy Systems – a sensitive interface



Prof. Dr. Ralf Ludwig

Department of Geography
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Germany
r.ludwig@lmu.de

ABBY-Net – Mission Statement

- The mission of ABBY-Net is to bring together researchers from Alberta, Canada and Bavaria, Germany who collaborate on interdisciplinary research and training for an improved understanding of the complex interactions in E^3-Systems (**E**nvironment, **E**ngineering and Socio-**E**conomics) to facilitate energy systems transitions (http://abby-net.org).

- ABBY-Net undertakes:

- international and interdisciplinary collaborative research projects
- collaborative training of highly qualified personnel
- regular summer schools held alternatingly in Bavaria and Alberta

ABBY-Net – Core Topics

Key research topics to facilitate energy transitions include:

- Cleaner energy production, transportation, and storage
- Impact of energy development on ecosystem processes
- Effects of changing environmental conditions on energy systems
- Advanced digital technologies in energy systems (research)
- Societal, economic and governance implications
- Interdisciplinary research designs

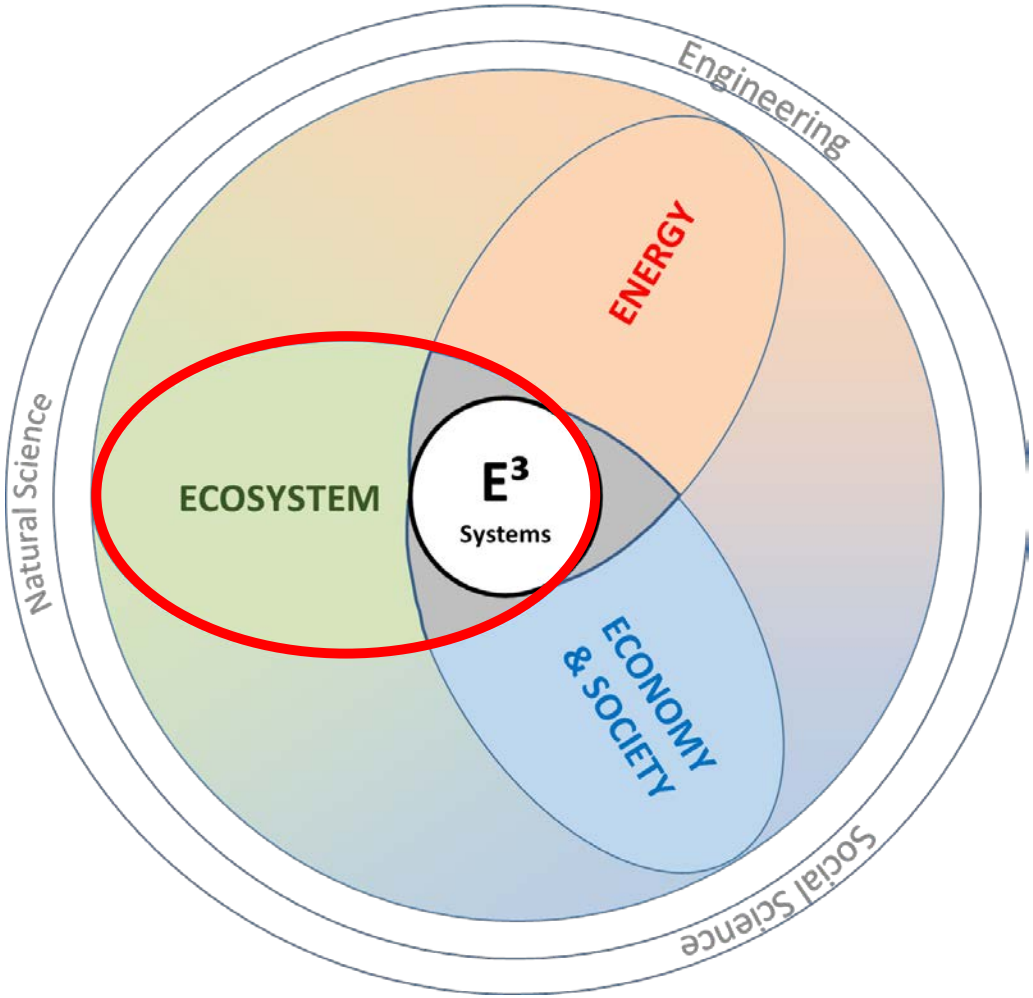
Key approaches include:

- New approaches to data analysis and artificial intelligence, including computer vision and machine learning
- New strategies of data acquisition and remote sensing technologies, such as (autonomous) drones
- Integrated modelling and evaluation systems designed for E^3-Systems (**E**nvironment, **E**ngineering and Socio-**E**conomics)

ABBY-Net – Current Activities

ABBY-E³-Systems - Facilitating Regional Energy Transitions

An E³ (Environment, Engineering, Economy) Approach



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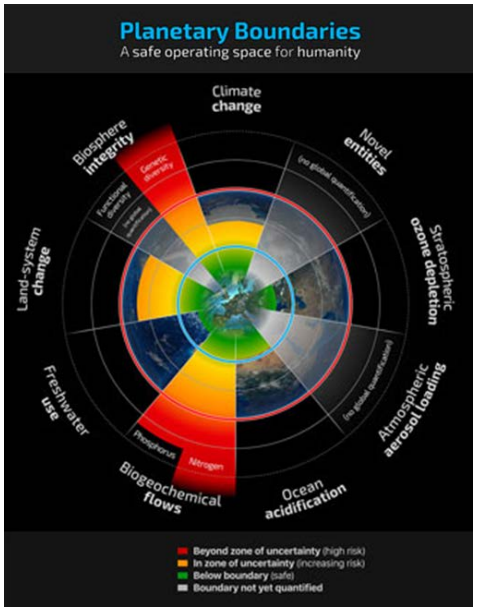

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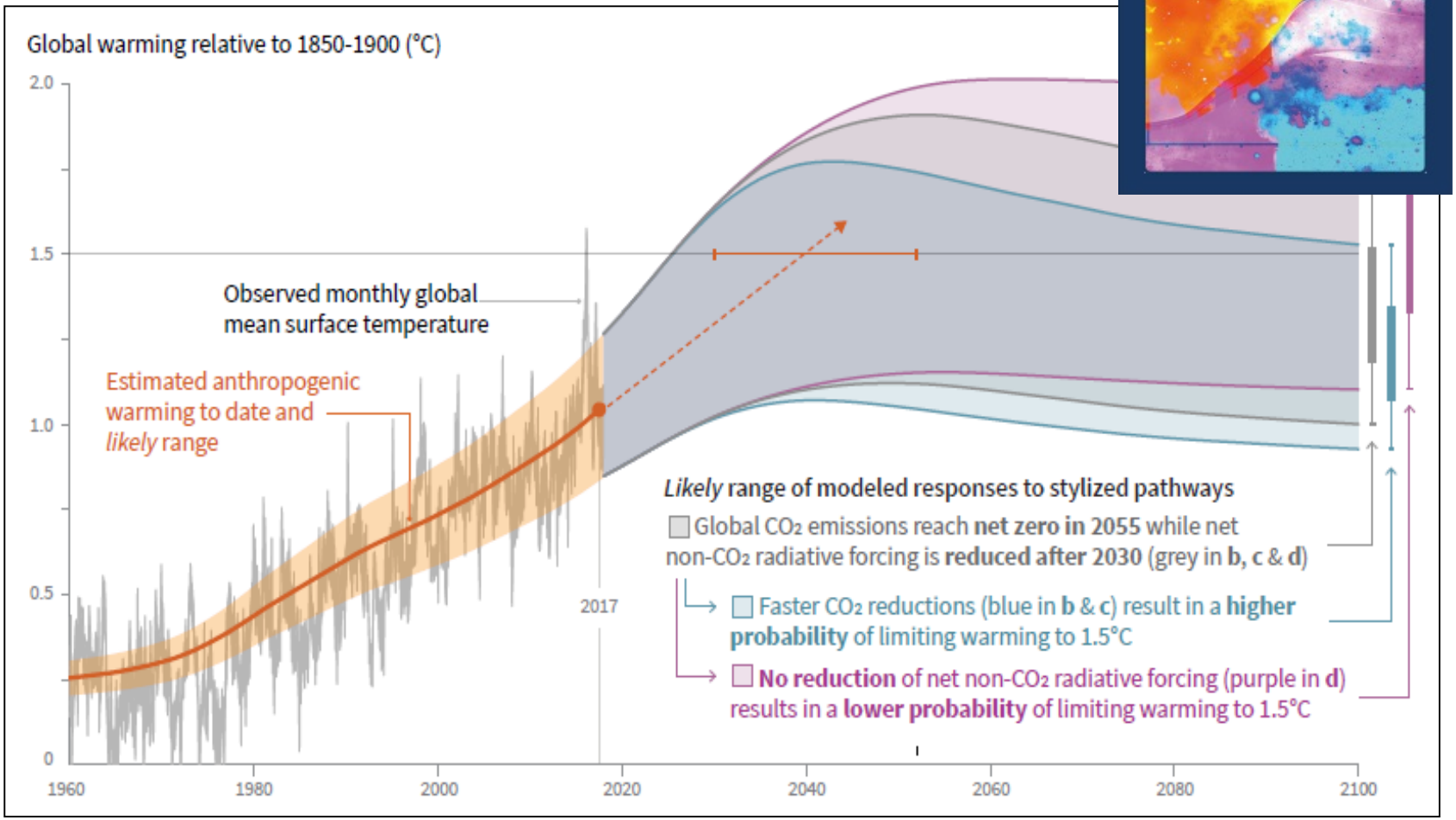
How is this connected to climate change?

Global emission trends… towards 1.5°C?



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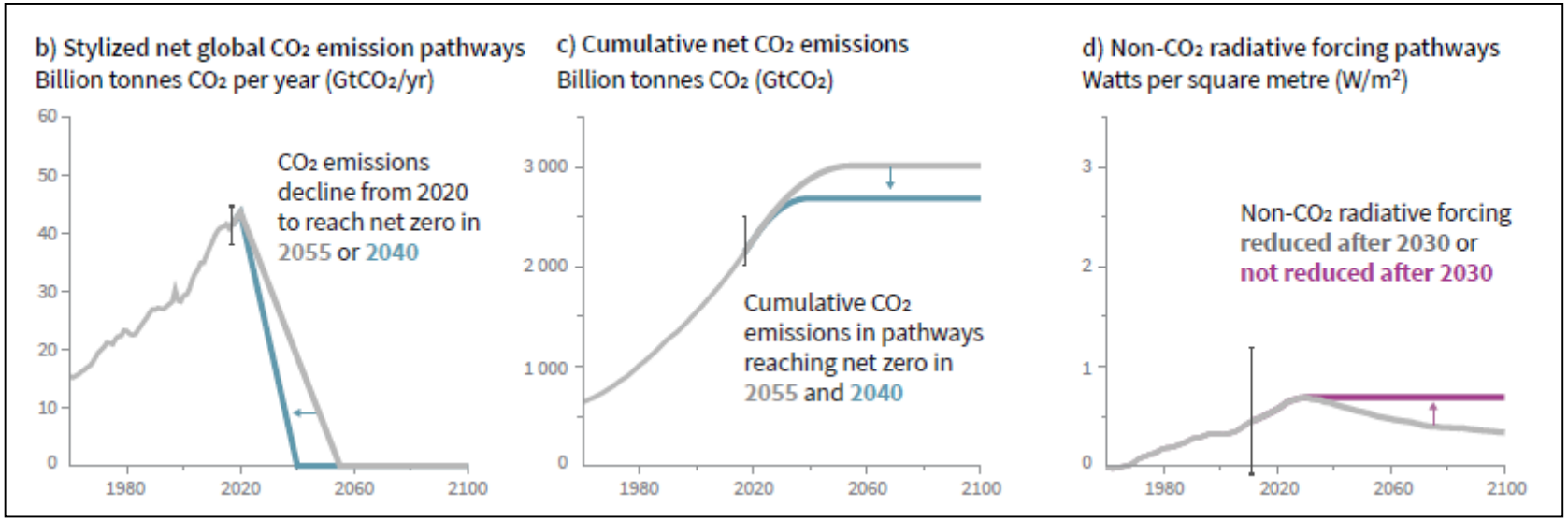
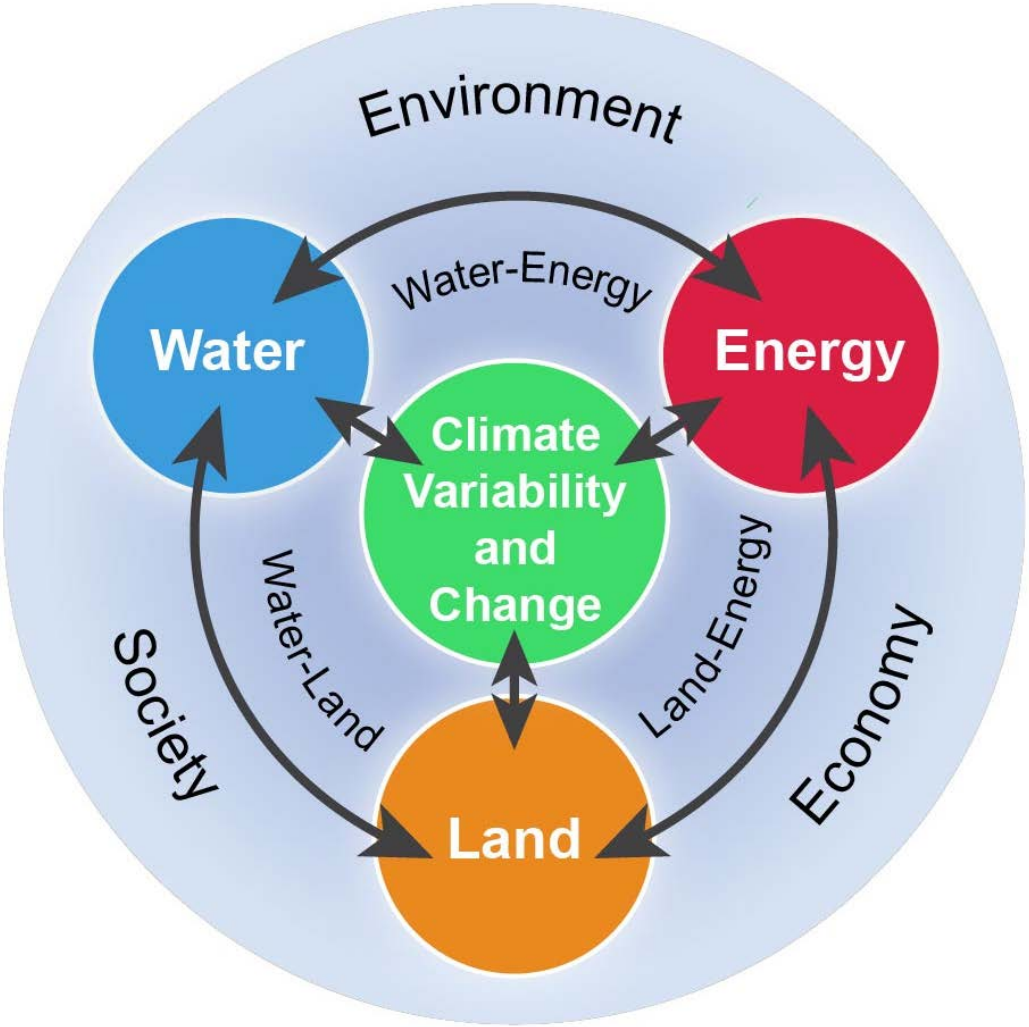
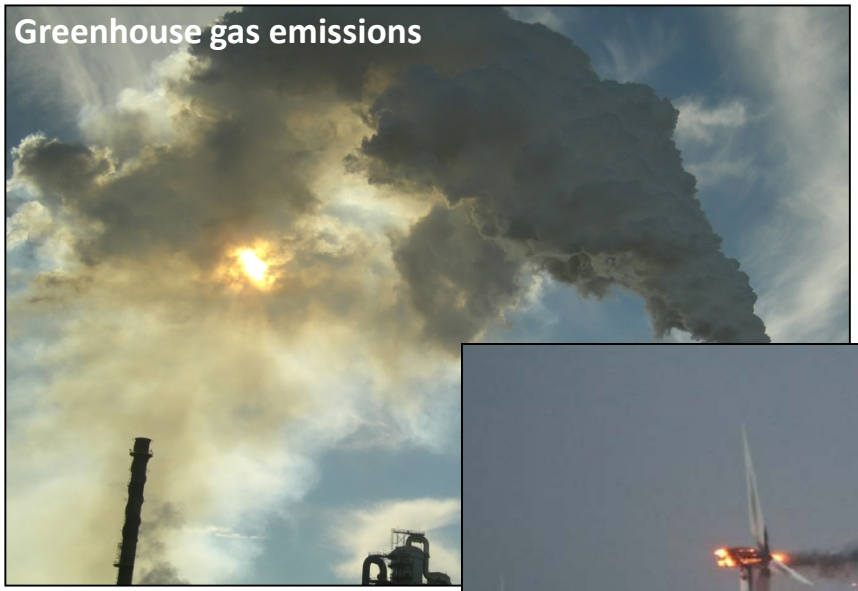


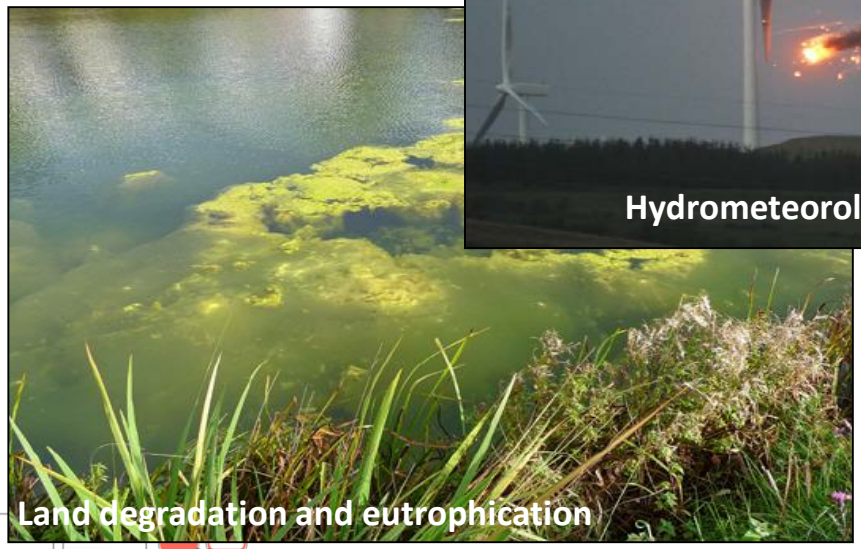
A systems thinking?



Skaggs et al. 2012

Energy systems and environmental impacts

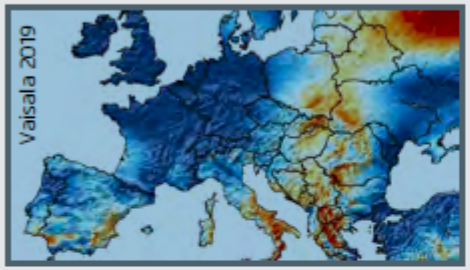




So, how this is connected? See Europe in 2018…

Wind

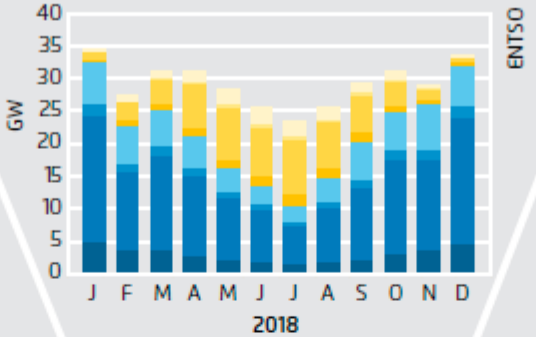
Wind generation during the heat-wave was low because the high pressure weather in July and August acted as a wall, stopping the wind from blowing in from the Atlantic to north-western Europe.

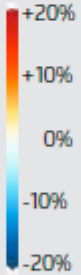


July 2018 wind speeds, anomalies to July averages for long-term average

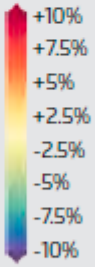
Wind & solar

Monthly wind and solar in 2018 in France, Germany, the Netherlands and the UK





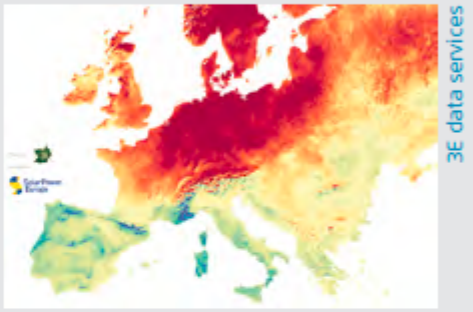
Solar replaced wind during the heatwave



Solar

The high pressure led to minimal cloud cover across NW Europe.

This meant solar was the only generation over-performing during the heatwave.



Jan–Dec 2018 solar radiation, anomalies to averages for the period 2004–2018

Nuclear

Water-cooled plants had to be shut down temporarily to protect rivers.

There were 4 complete shut-downs in France (Saint-Alban-1 1335MW, Bugey-2 & -3, 910MW, Fessenheim-2 920MW), one in Sweden (Ringhals, 900MW), plus numerous plants trimmed their output across Europe.

Effects of the 2018 heatwave

Demand

The heatwave led to high demand for air conditioning. Poland reached its highest ever demand in summer on June 4th of 23.2GW.

The Potsdam Institute predicted that peak demand in many European countries will shift from winter to summer, as air conditioning rises, due to higher penetration and due to climate change.

(© AGORA Energiewende 2019)

So, how this is connected? See Europe in 2018…

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-20%

-7.5%
-10%

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Hard coal

From August to November 2018, 12 plants in Germany along the Rhine alone reported supply shortage problems, because the Rhine levels was too low to import coal by barge.

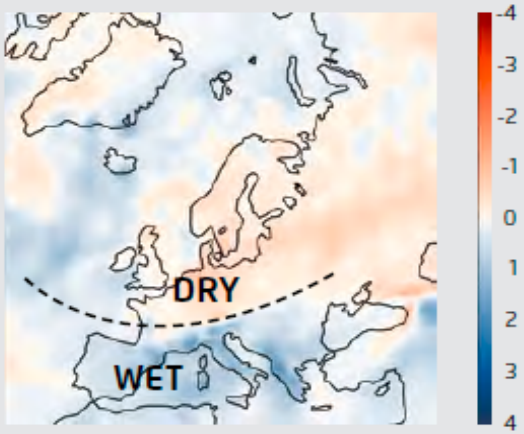
There were also problems with cooling water: Karlsruhe-7 (Germany, 505 MW) had to shut down because they were prohibited to empty their warm cooling water in the Rhine.

Hydro

Low hydro generation in northern Europe, due to below-average rainfall throughout the year:

- → Austria: lowest in eight years
- → Sweden: lowest in six years
- → Germany: lowest this century

Jan–Dec 2018 precipitation (mm/day), anomalies to averages for the period 1981–2010



ECMWF Copernicus Climate Change Service 2018

(© AGORA Energiewende 2019)

Current research…

Assessing the impacts of climate change and climate variability on hydrological extreme events

Ralf Ludwig, Andrea Böhnisch,
Magdalena Mittermeier, Ben Poschlod,
Fabian von Trentini, Florian Willkofer, Raul Wood

on behalf of many outstanding project partners!

gefördert durch
Bayerisches Staatsministerium für
Umwelt und Verbraucherschutz

Motivation

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

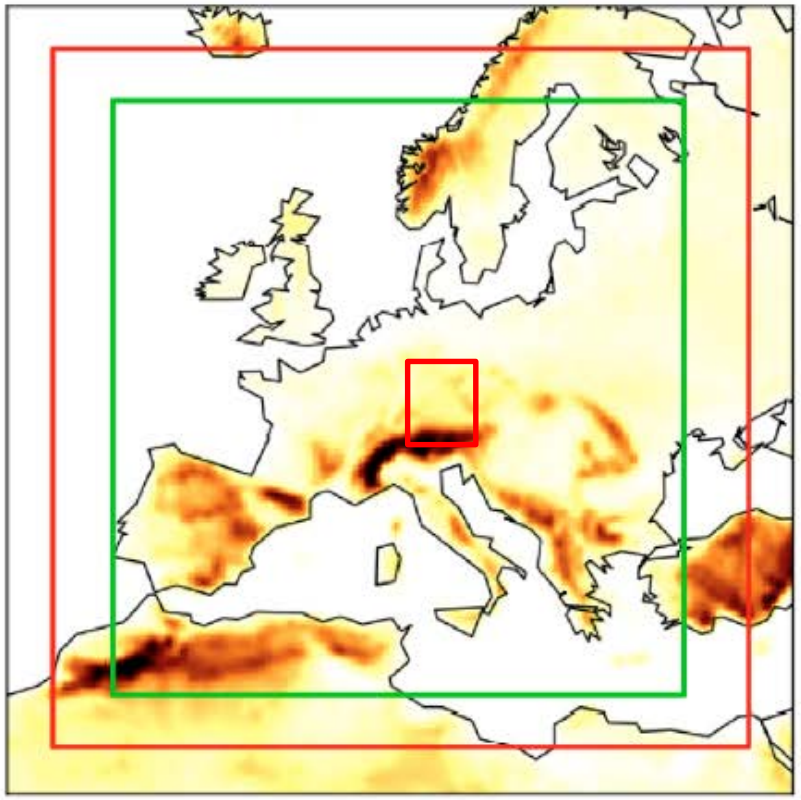
Major flood events in Bavaria
1999/2002/2005/2013/2016

« Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent. » - IPCC AR5 report

ClimEx – Research objectives

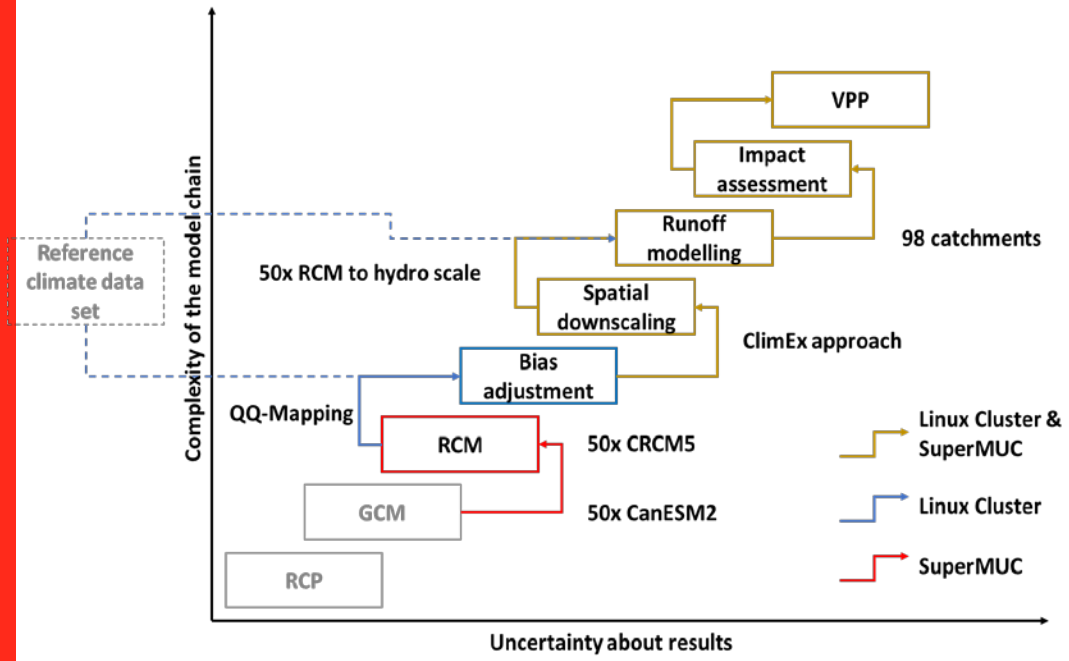
- Does climate change contribute to higher intensities and frequencies of hydro-meteorological extreme events? If yes, how?
- How can we distinguish between the effects of natural variability and a “clear” climate change signal?
- Which impacts on water and energy resources must be expected (for Bavaria)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

ClimEx – Case studies



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

ClimEx – Concept and methods



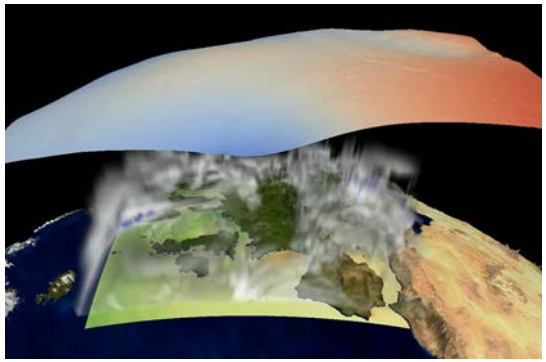
Method: Novel process chain from regional climate model ensemble (LMU, Ouranos) to process-based impact models (LMU, INRS, ETS) and practical evaluation of results (LfU, CEHQ), utilizing massive HPC and Big Data (LRZ)

- 50 model members, i.e. 50 possible climate pathways (1950-2099

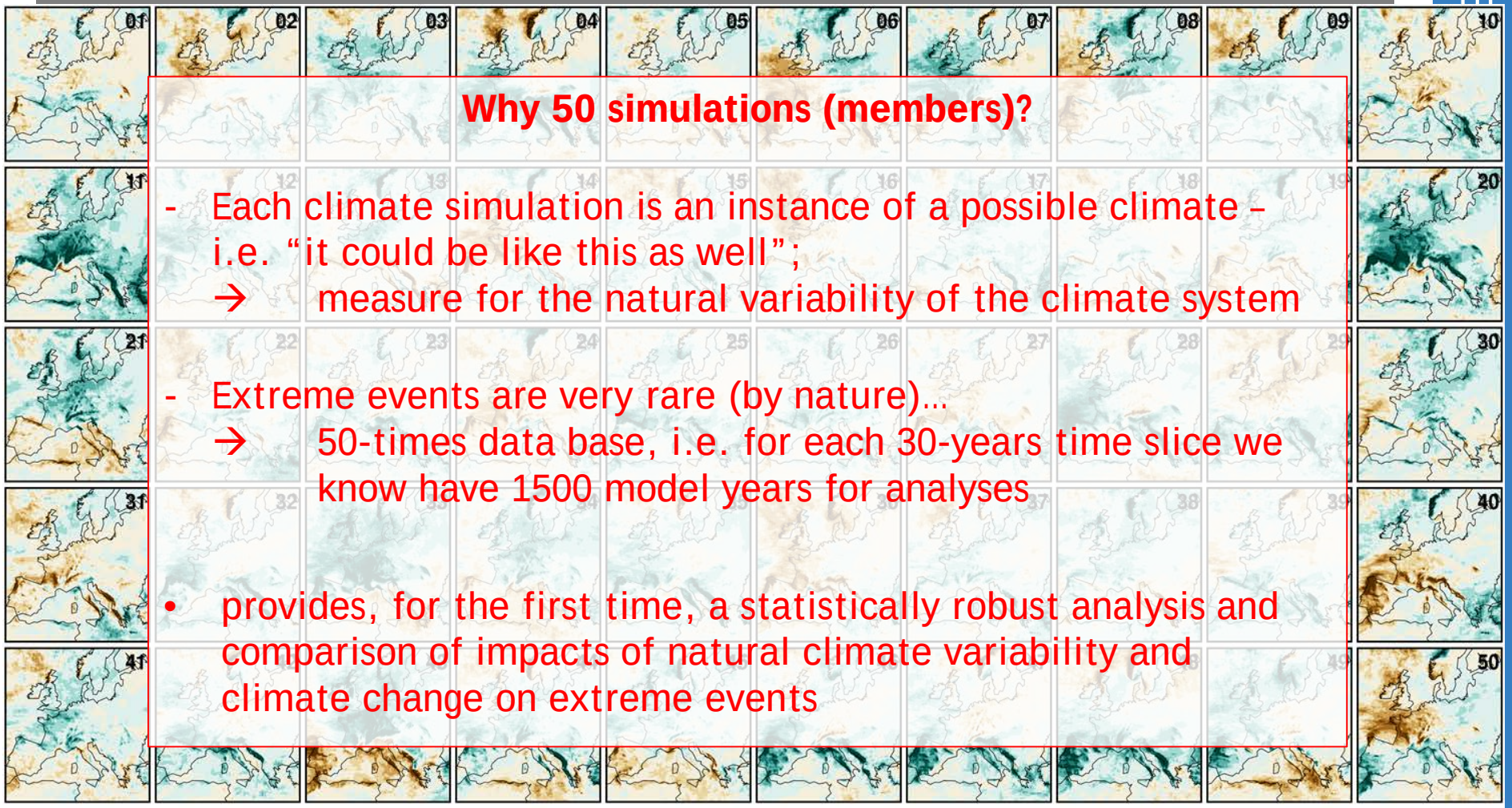
→ 7500 model years (+ 700 model years of counterfactual world)

HPC & (really) Big Data…

- ~ 100 MCPU-h, 500 Tbyte (*2 Backup)
- Data Science Storage (DSS)
- 1 year of computation on SuperMUC
- 1.25 GWh of electricity…



Natural climate variability

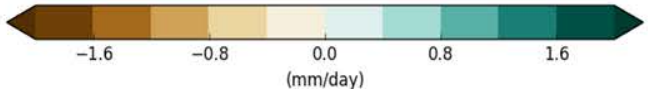


Why 50 simulations (members)?

- 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

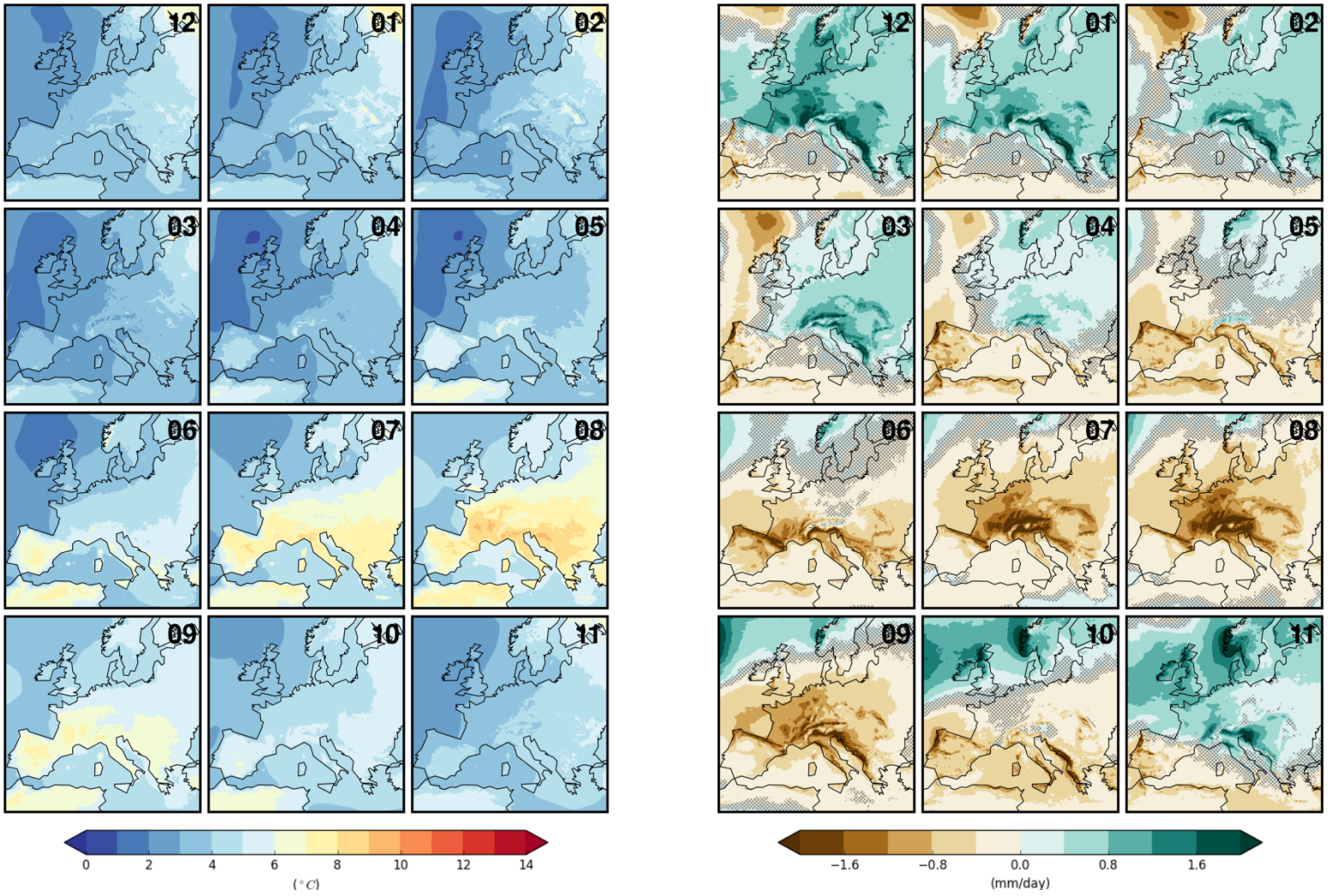
- Extreme events are very rare (by nature)…
  → 50-times data base, i.e. for each 30-years time slice we know have 1500 model years for analyses

- provides, for the first time, 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

Climate Change Signals – prcp & temp over Europe



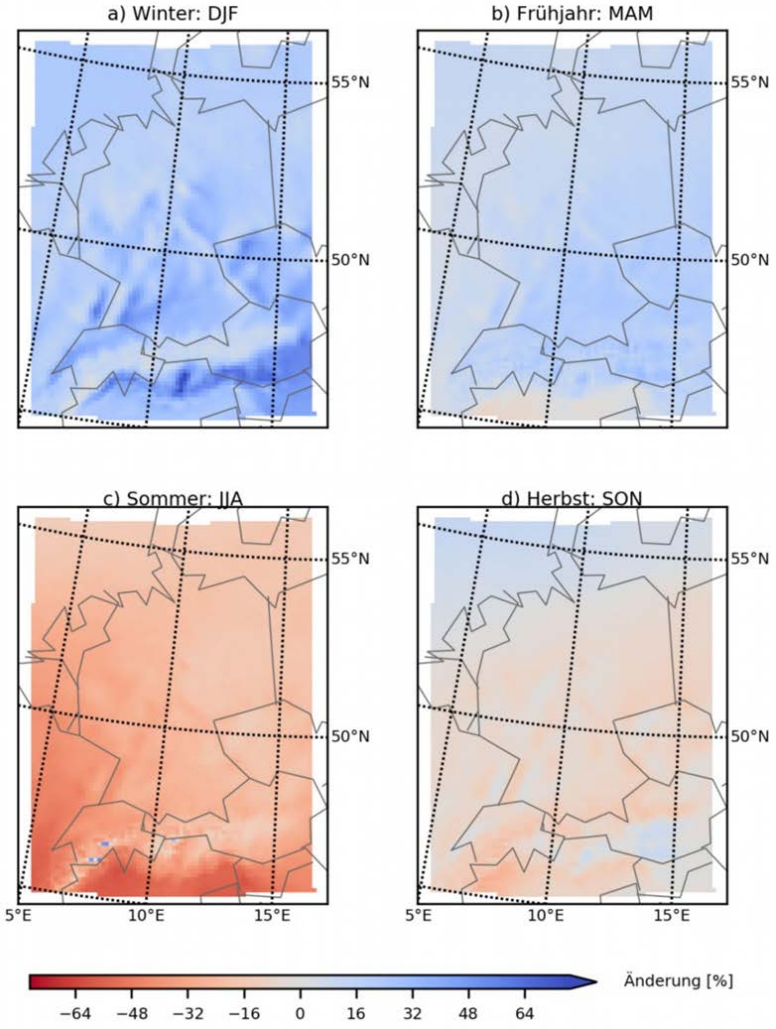
Monthly change of temperature and precipitation (2080-2099 vs. 2000-2019)
(50 member mean)

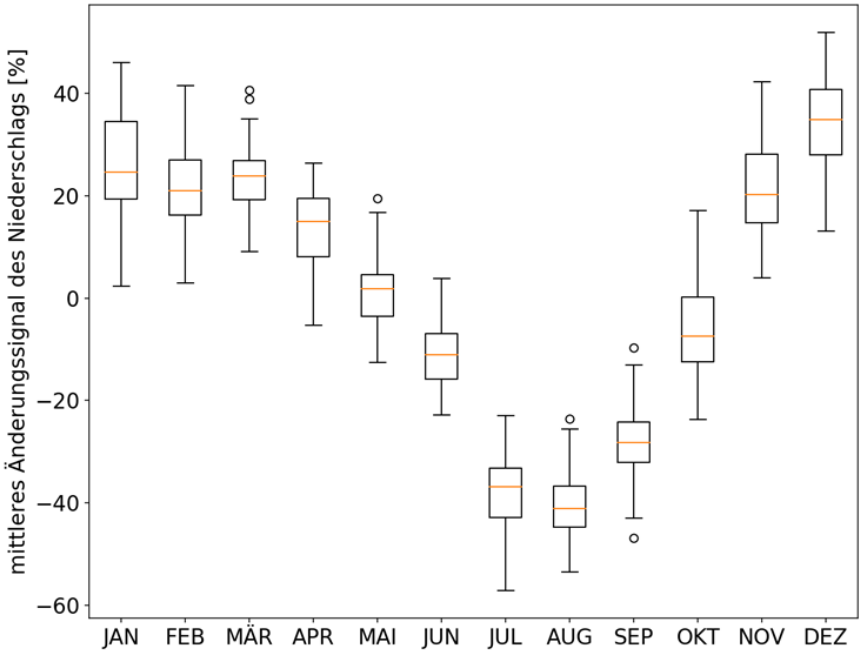
(© Martin Leduc)

Precipitation

Looking at Central Europe…

(Strong) Changes in the seasonal precipitation distribution!

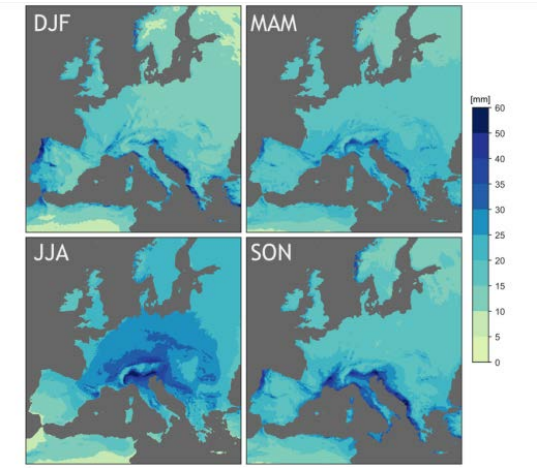


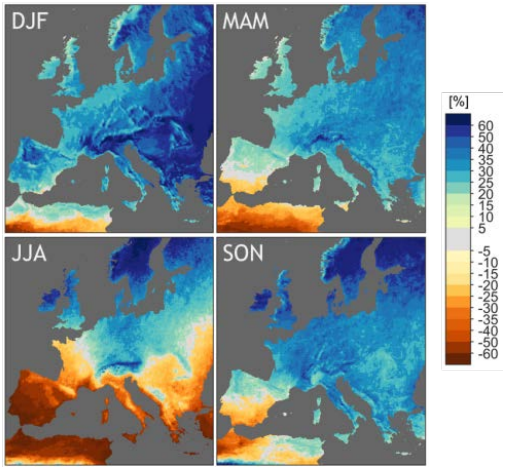


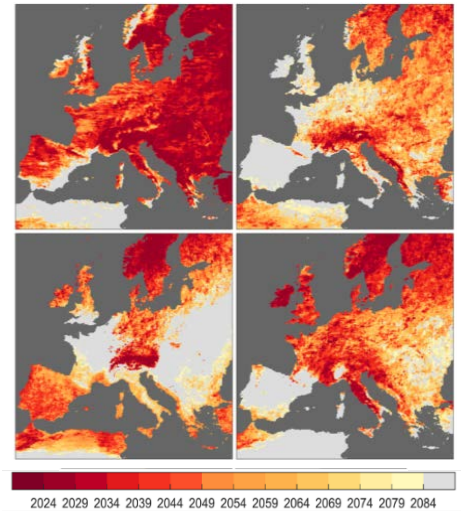
Winters will be much wetter!

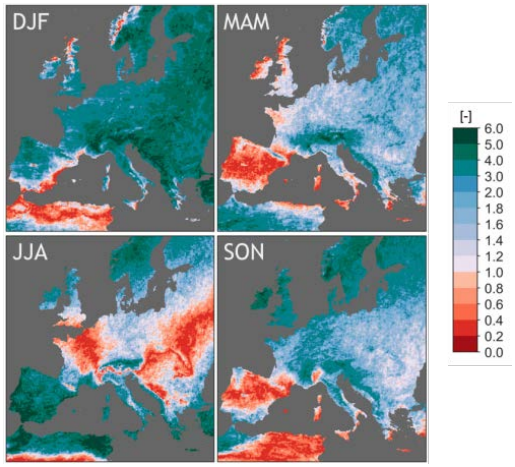
Summers will be much dryer!

Extreme precipitation over Europe – Rx3h









Maximum 3h-precipitation (Rx3h)

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

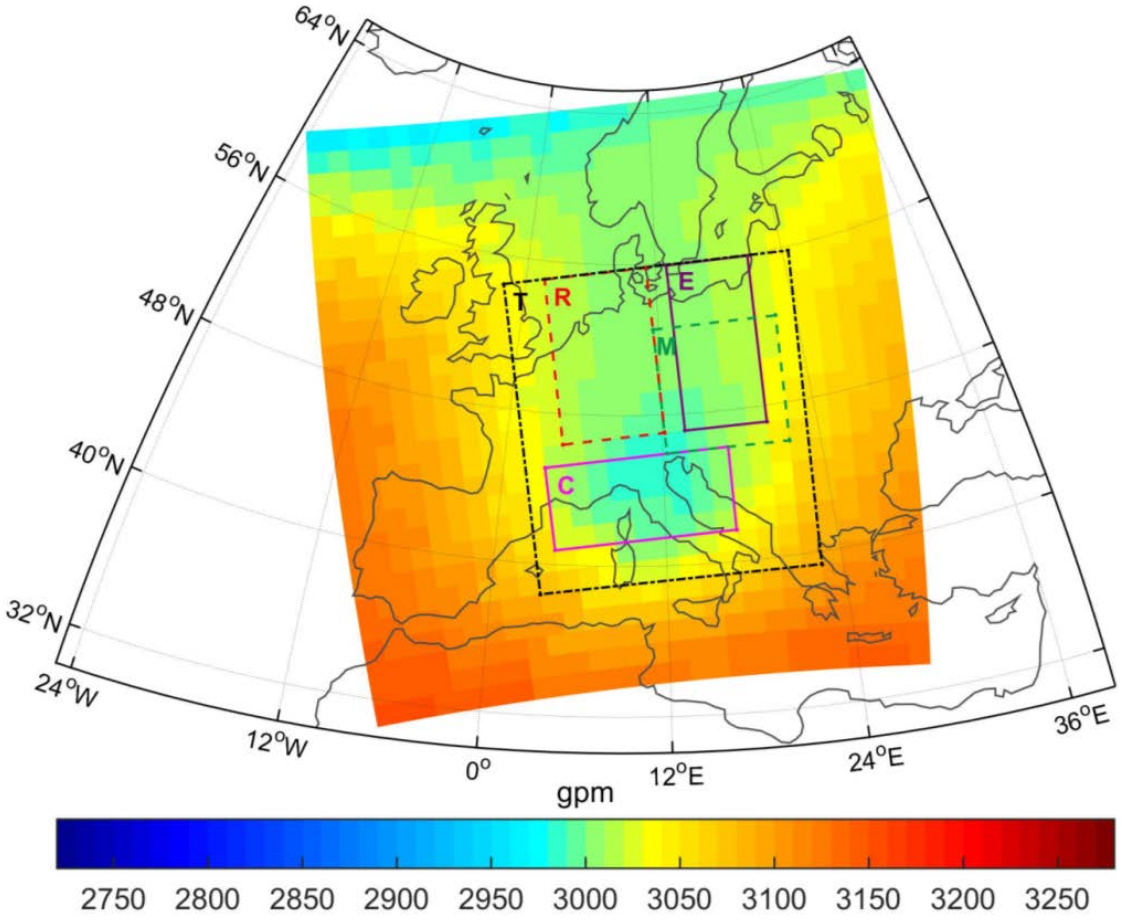
b) climate change signal (%) (future period 2070-2099)

c) strong geographical differences in S/N – Ratio (2070-2099)

d) calculation of Time of Emergence (when S/N >1)

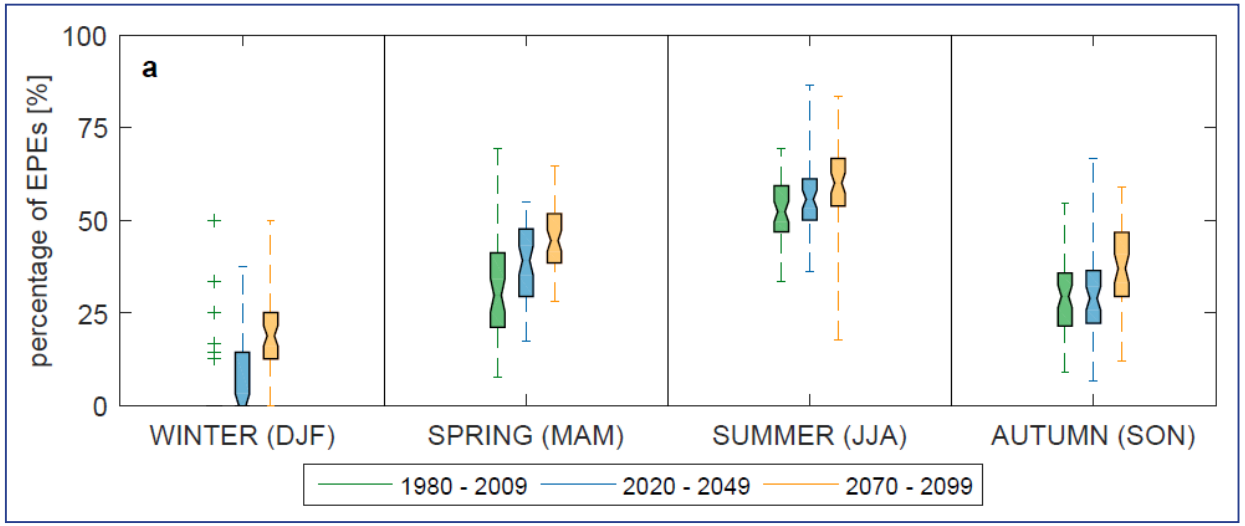
(after Wood & Ludwig, 2020, *GRL*)

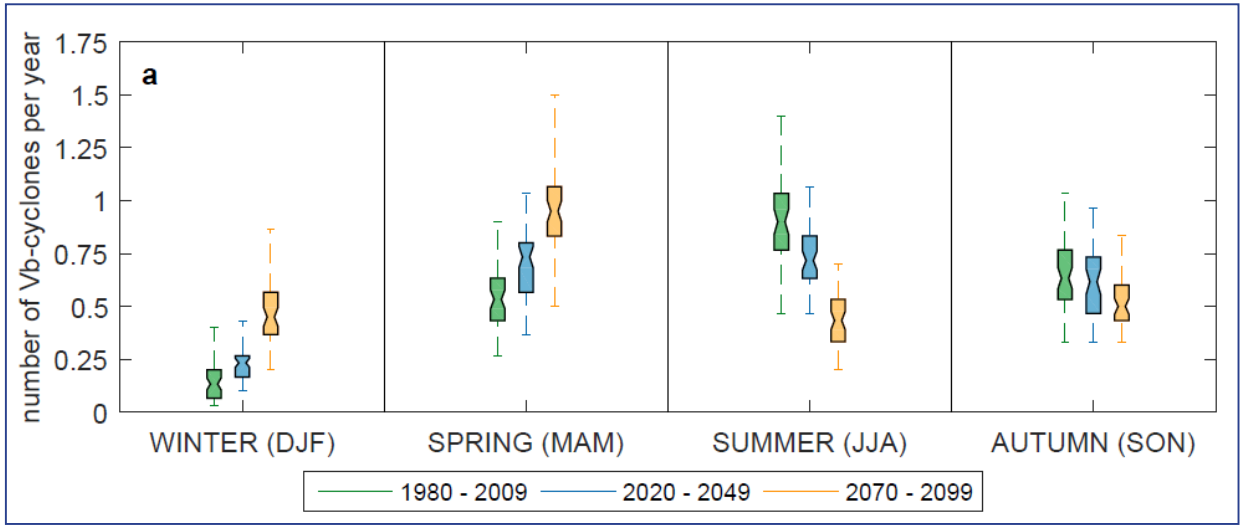
Weather patterns – Vb cyclones



(Mittermeier et al., 2019, *GRL*)

Weather patterns – Vb cyclones





Increasing relevance for extreme precipitation events (EPE) linked to Vb-tracks in all seasons

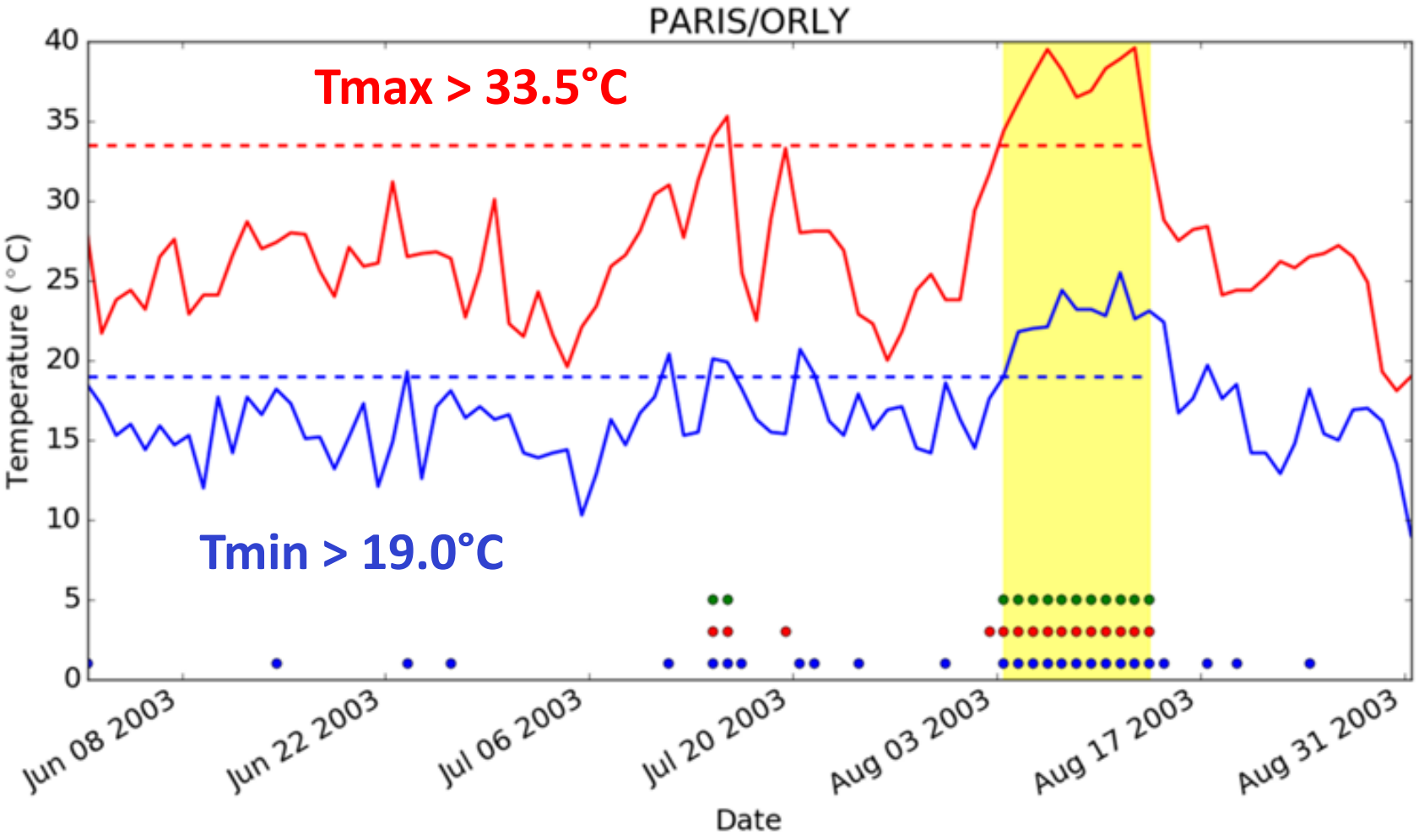
Significant seasonal shifts of Vb-related EPEs from summer to spring

(Mittermeier et al., 2019, *GRL*)

Heat

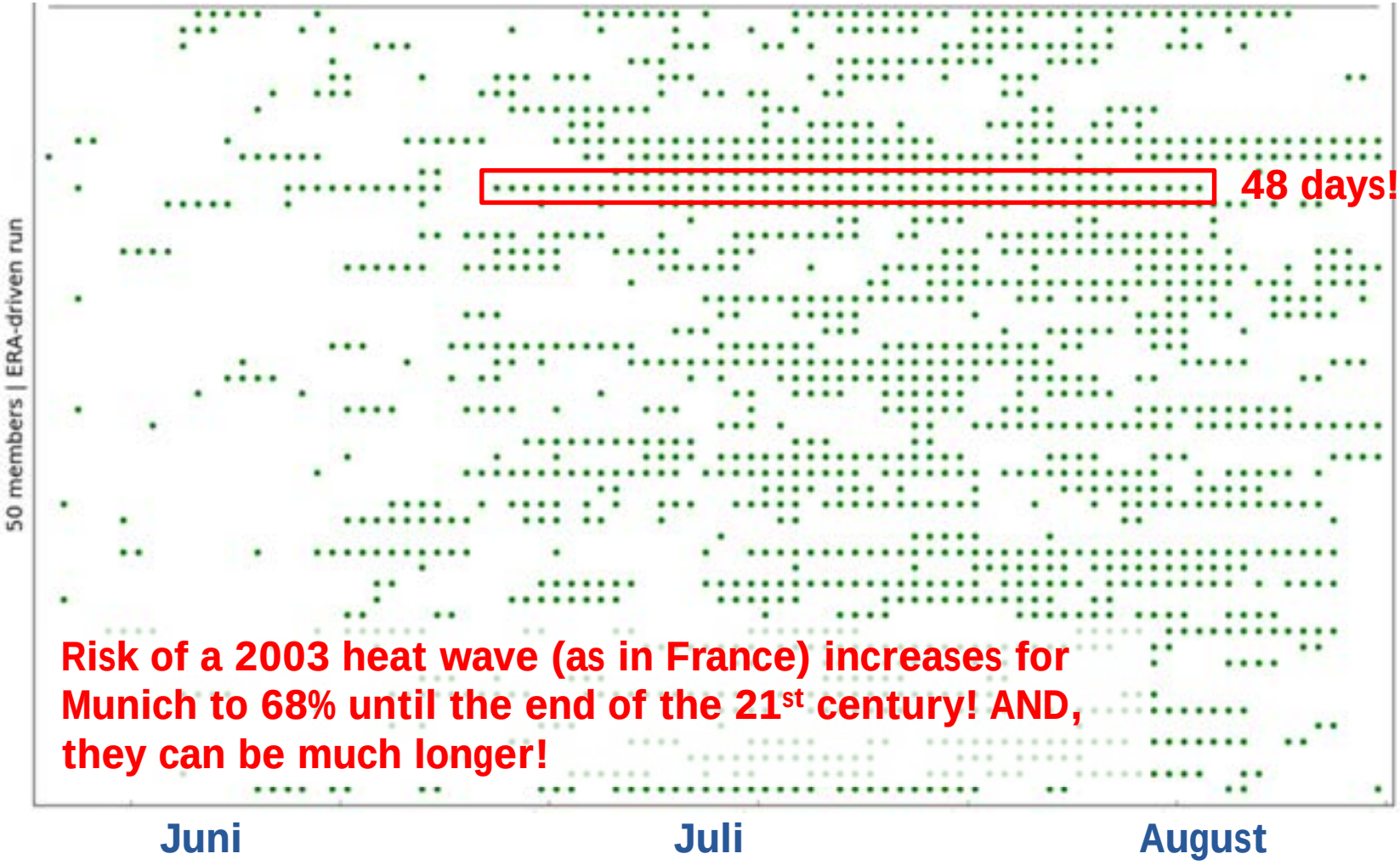
Heat in Munich…

The example from France in 2003…



Heat in Munich…

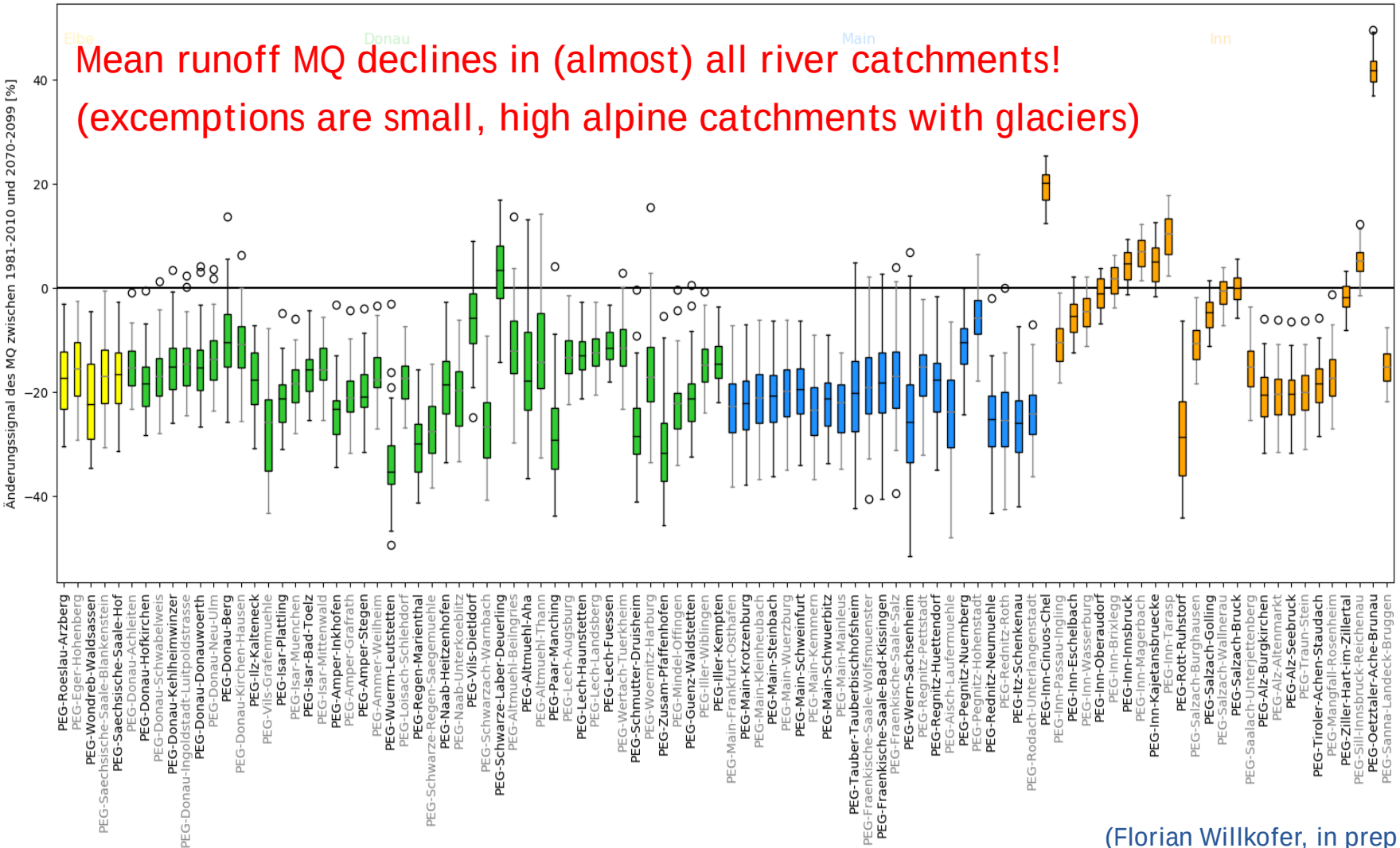
… applied to Munich in 2099 …



Runoff and Floods

Changes in Mean Runoff

Difference [2070-2099] – [1981-2010]



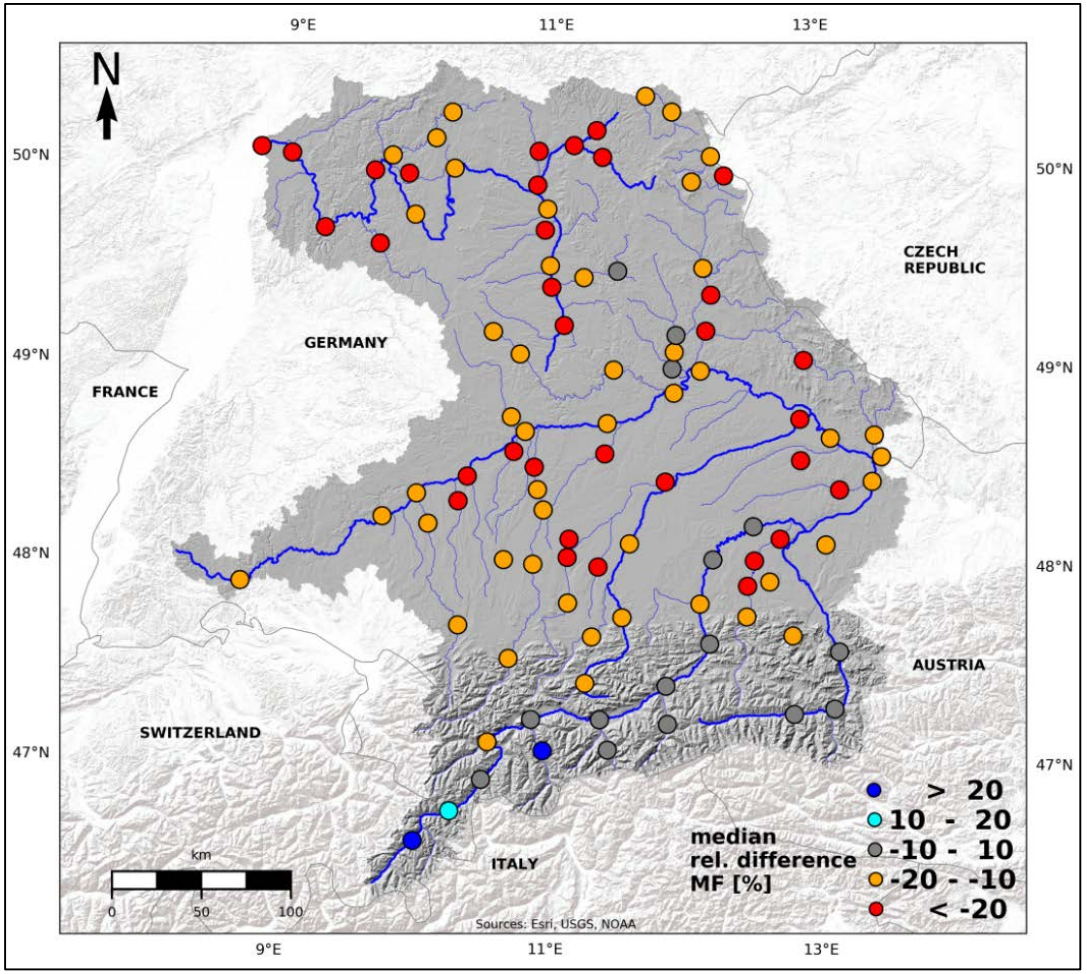
(Florian Willkofer, in prep.)

Changes in Mean Runoff

Difference [2070-2099] – [1981-2010]

Mean runoff MQ declines in (almost) all river catchments!

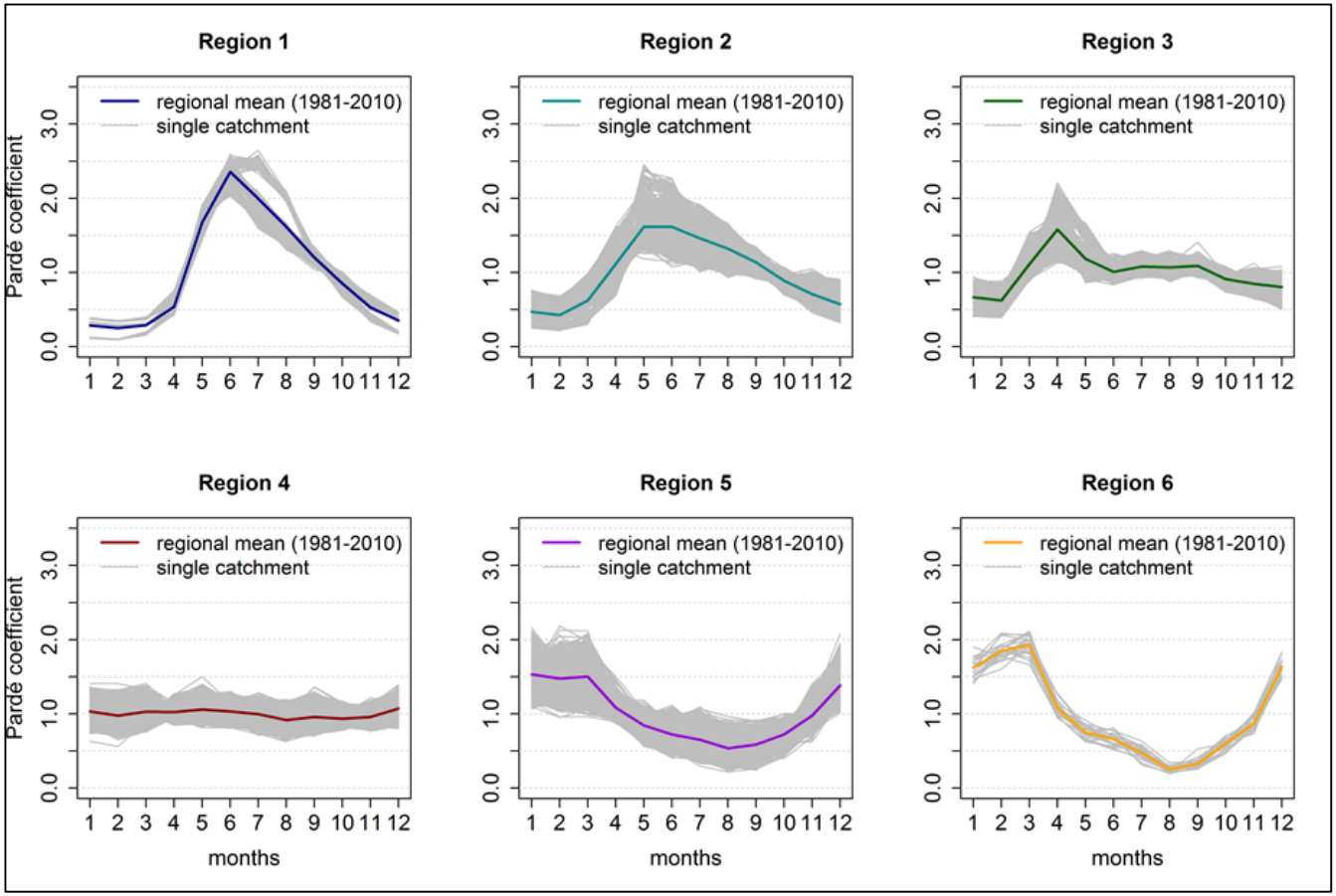
(exemptions are small, high alpine catchments with glaciers)



(Florian Willkofer, in prep.)

Changes in Runoff Patterns and Regimes

Change in runoff characteristics (Pardé regimes) in Bavarian river basins



(Poschlod et al., 2020, *Water*)

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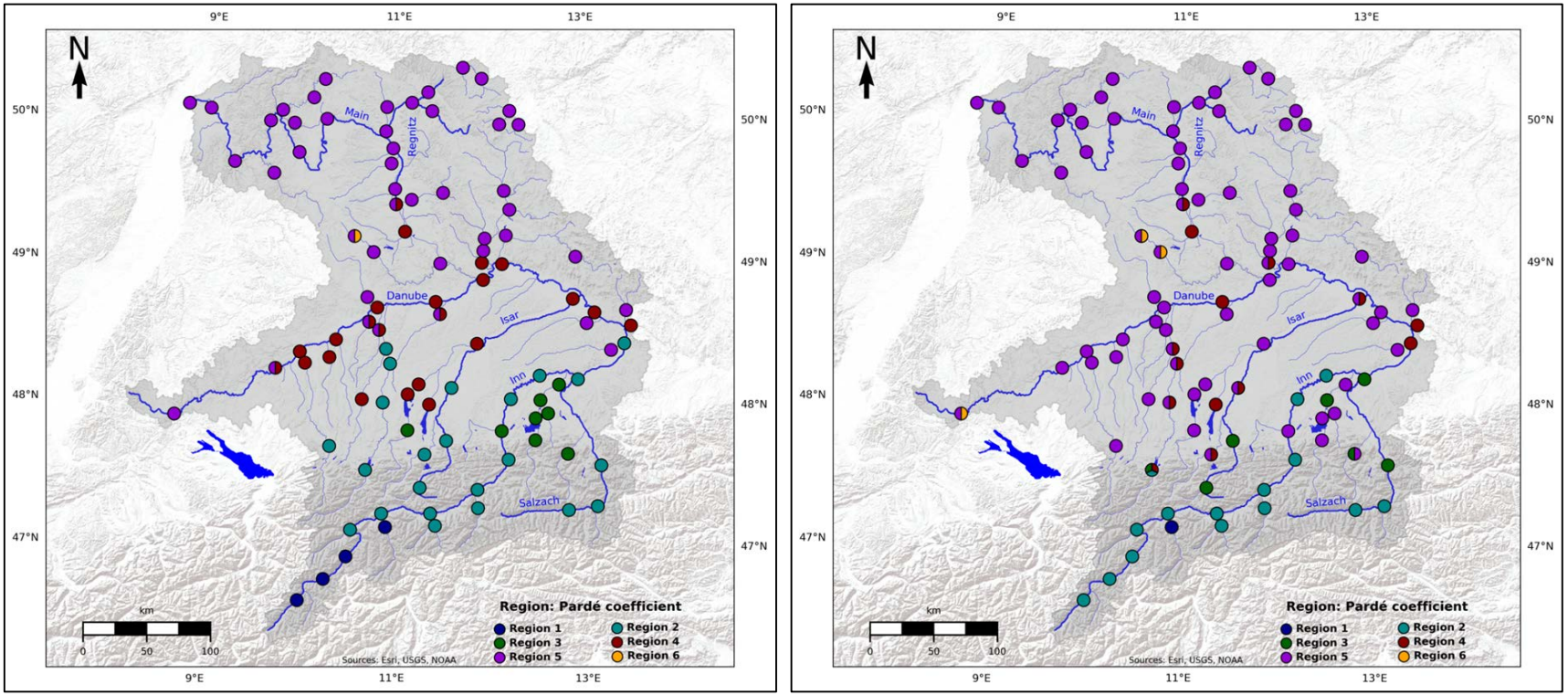
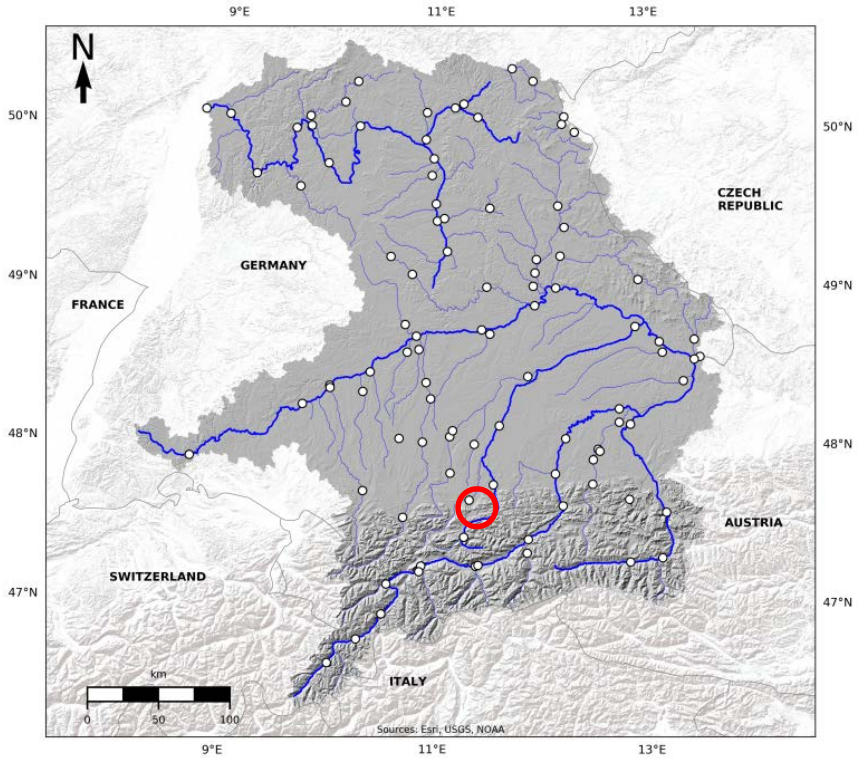
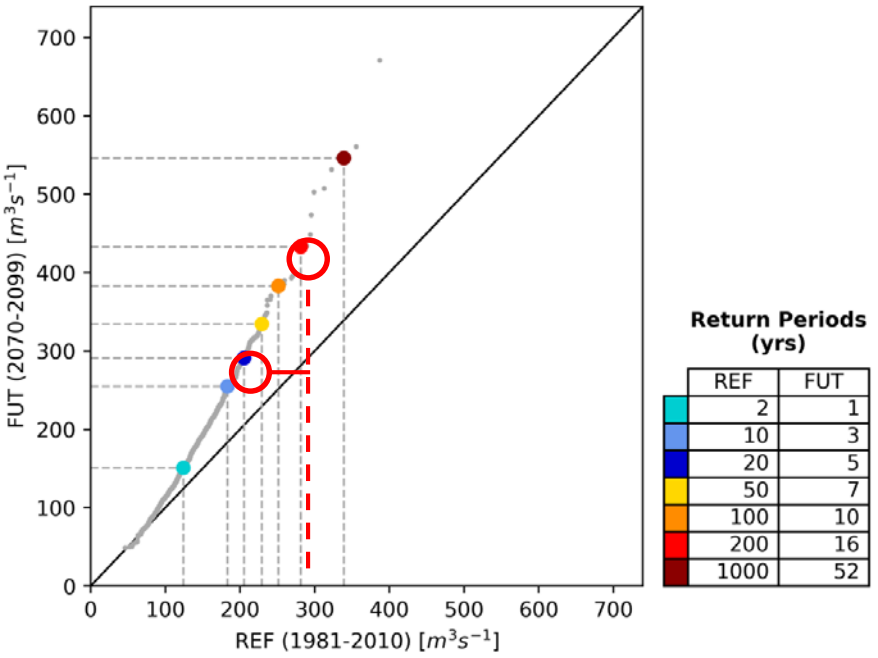


(Poschlod et al., 2020, *Water*)

Extreme Floods – looking ahead…

Will high return periods become more frequent and intense?





Intensity → change in discharge of a reference return period in the future

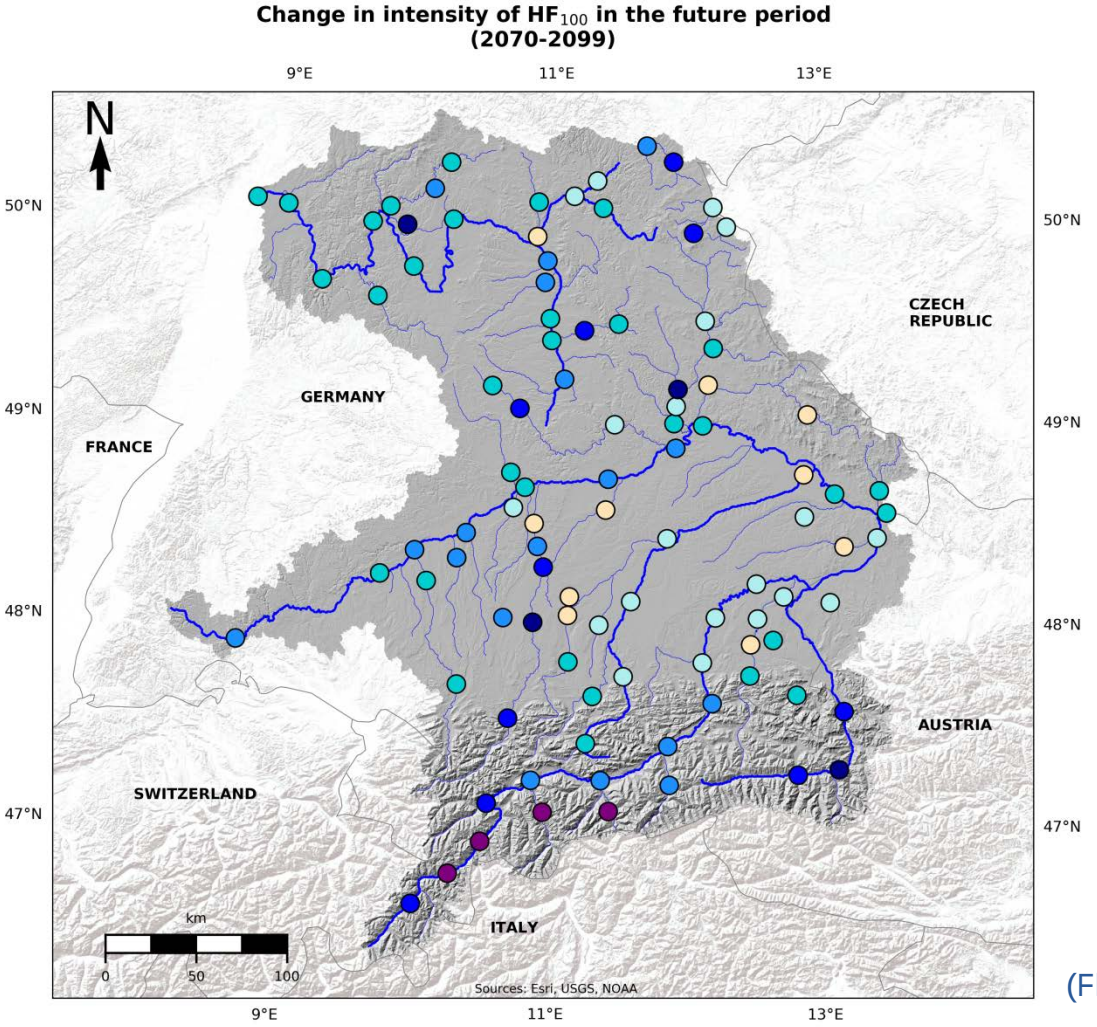
250 m^3/s → **390 m^3/s**

100-year → **10-year**

Frequency → change in return period from reference to future

Extreme Floods – looking ahead…

Will high return periods become more frequent and intense?



Intensity

2070-2099 vs. 1981-2010

Change in HF100 intensity [%]

> 50	0 - -10
40 - 50	-10 - -20
30 - 40	-20 - -30
20 - 30	-30 - -40
10 - 20	-40 - -50
0 - 10	< -50

increase in intensity

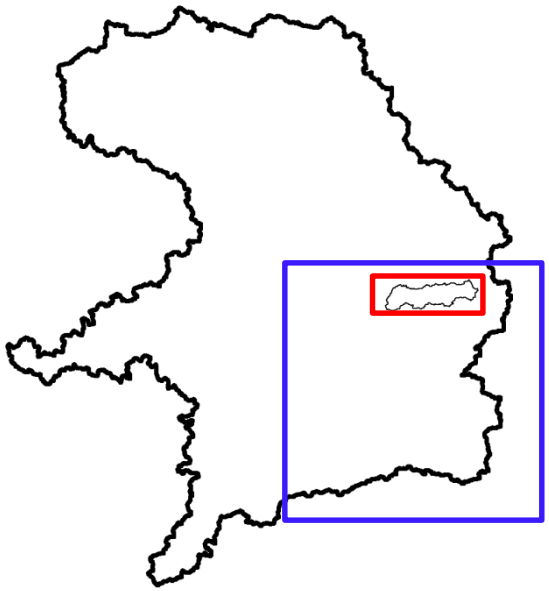
decrease in intensity

(Florian Willkofer, Raul Wood)

Extreme Floods – looking ahead…

Which processes might induce extreme high flow events? - compound events

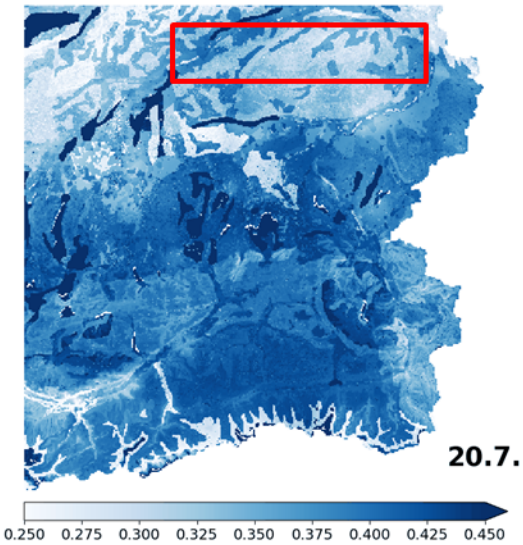
Illustration of a
compound event



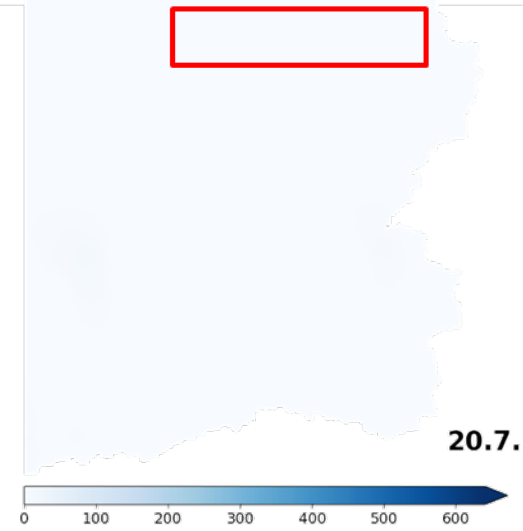
Catchment:
Rott - Ruhstorf

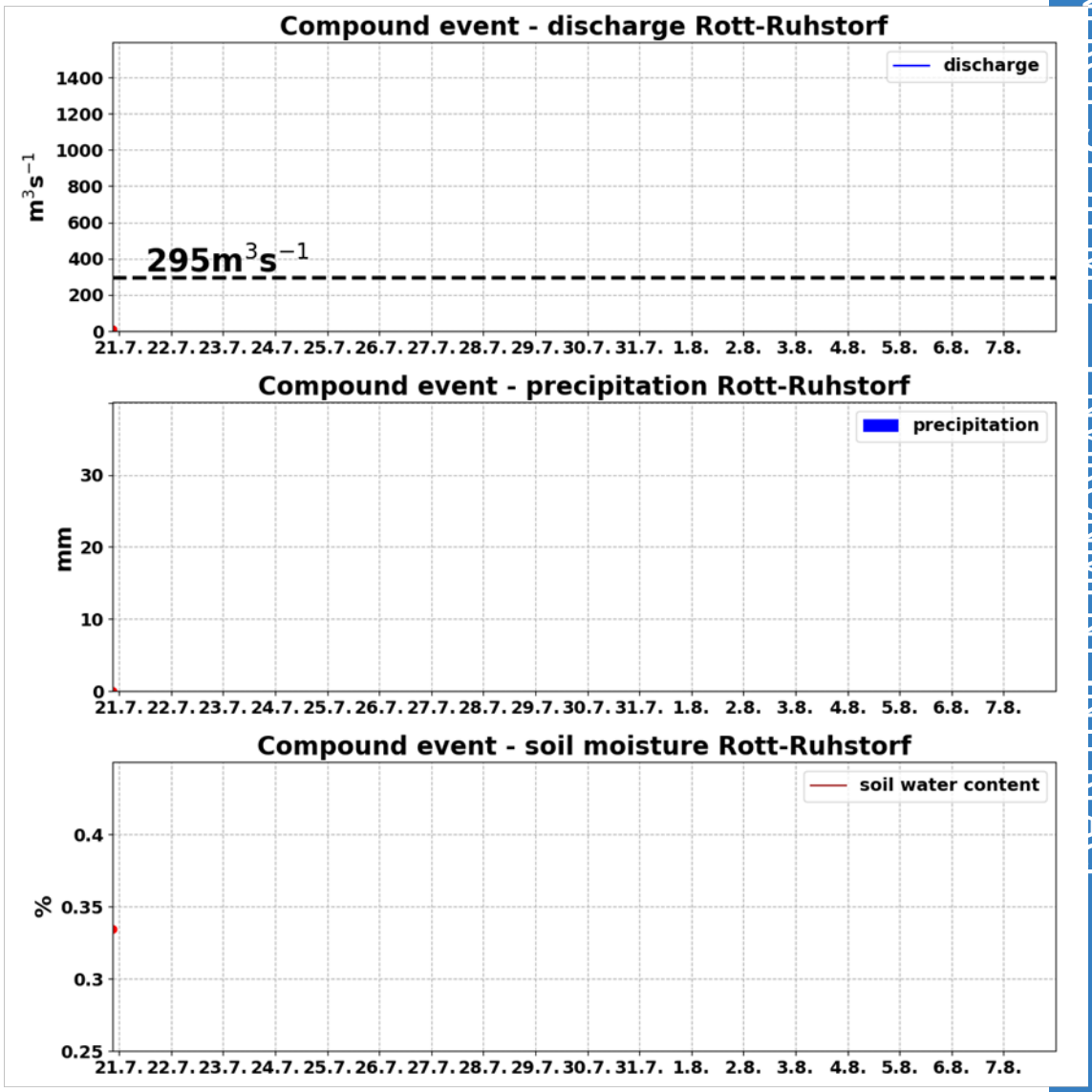
Extreme Floods – looking ahead…

Soil water content root zone



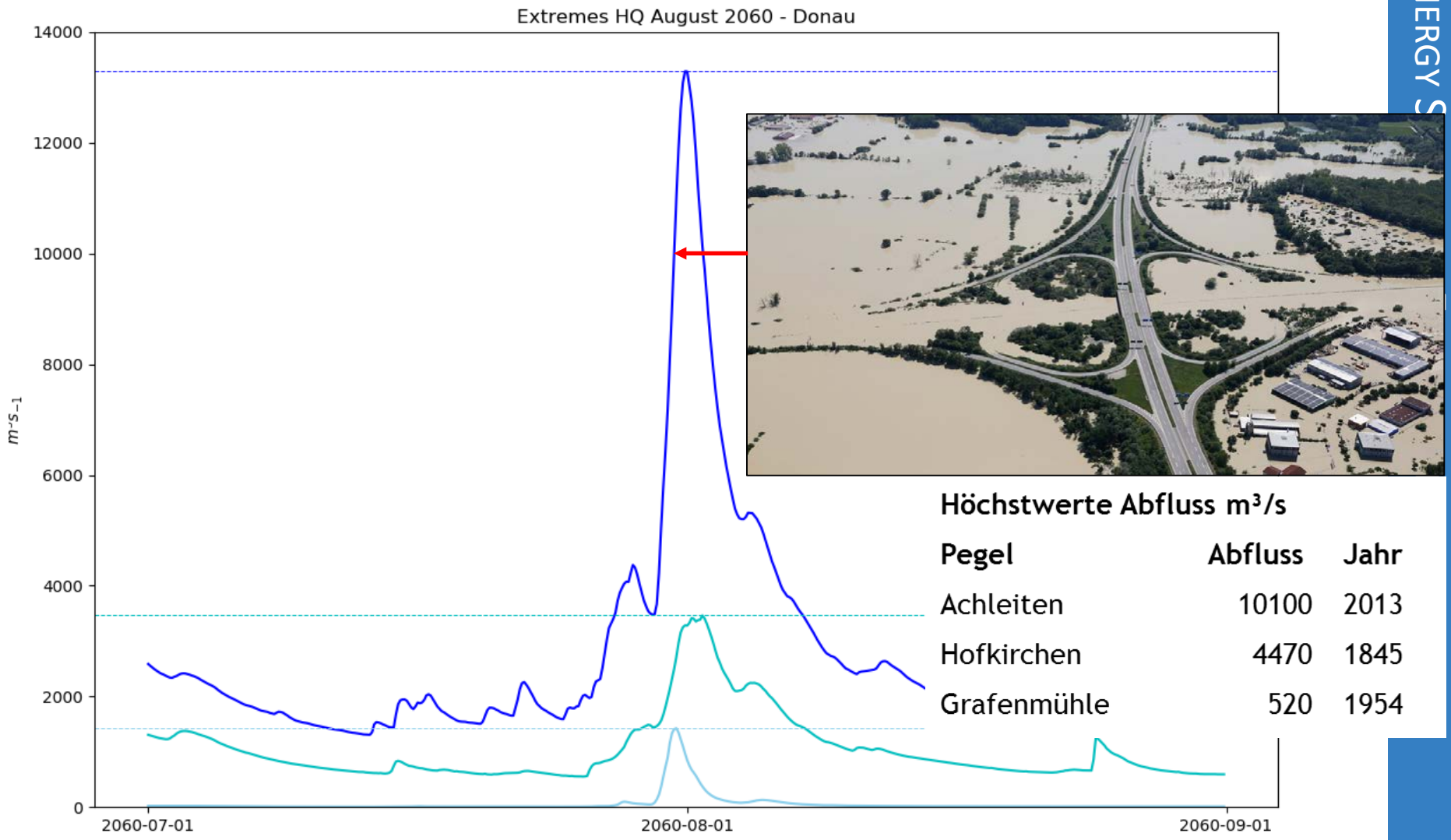
Cumulative sum of precipitation





(© Florian Willkofer)

Extreme Floods – looking ahead…



Höchstwerte Abfluss m³/s

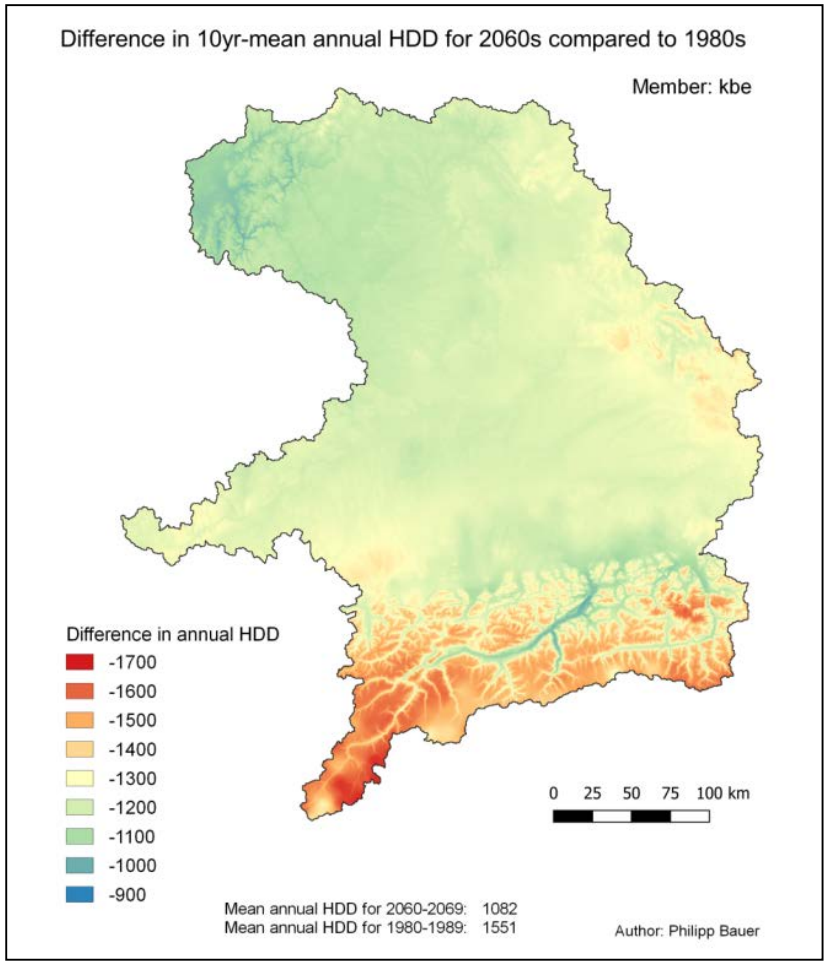
Pegel	Abfluss	Jahr
Achleiten	10100	2013
Hofkirchen	4470	1845
Grafenmühle	520	1954

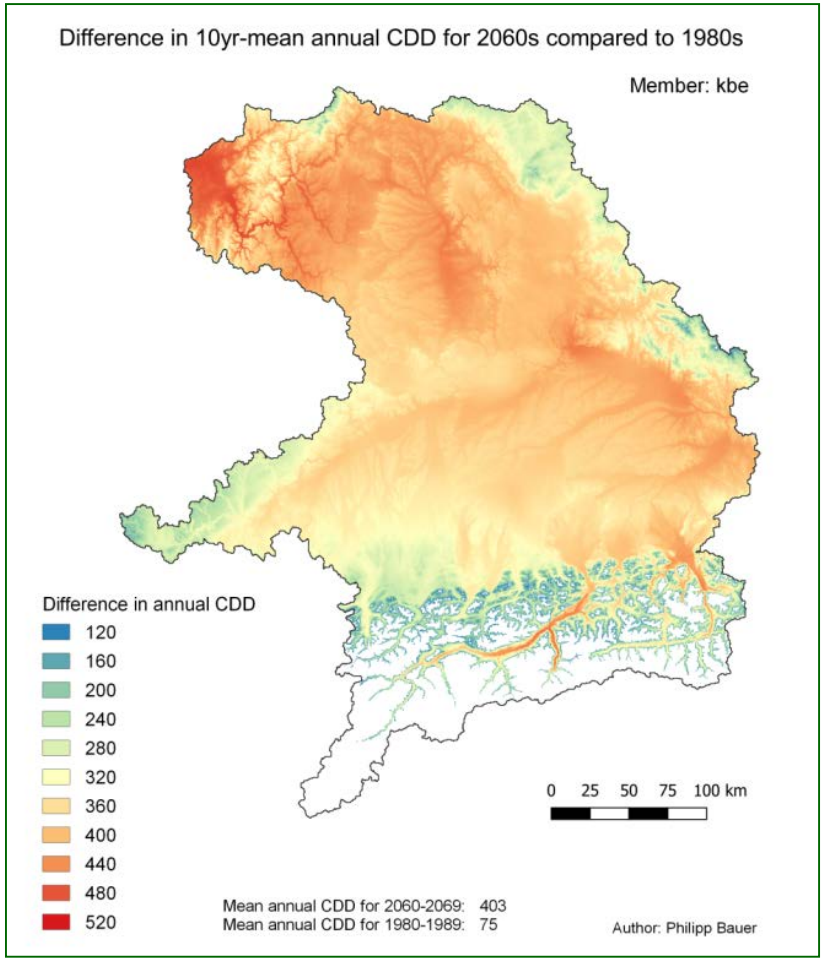
(© Florian Willkofer)

Energy

Impacts of climate change on energy demand

Heating and Cooling Degree Days … Bavaria (end of 21st century)





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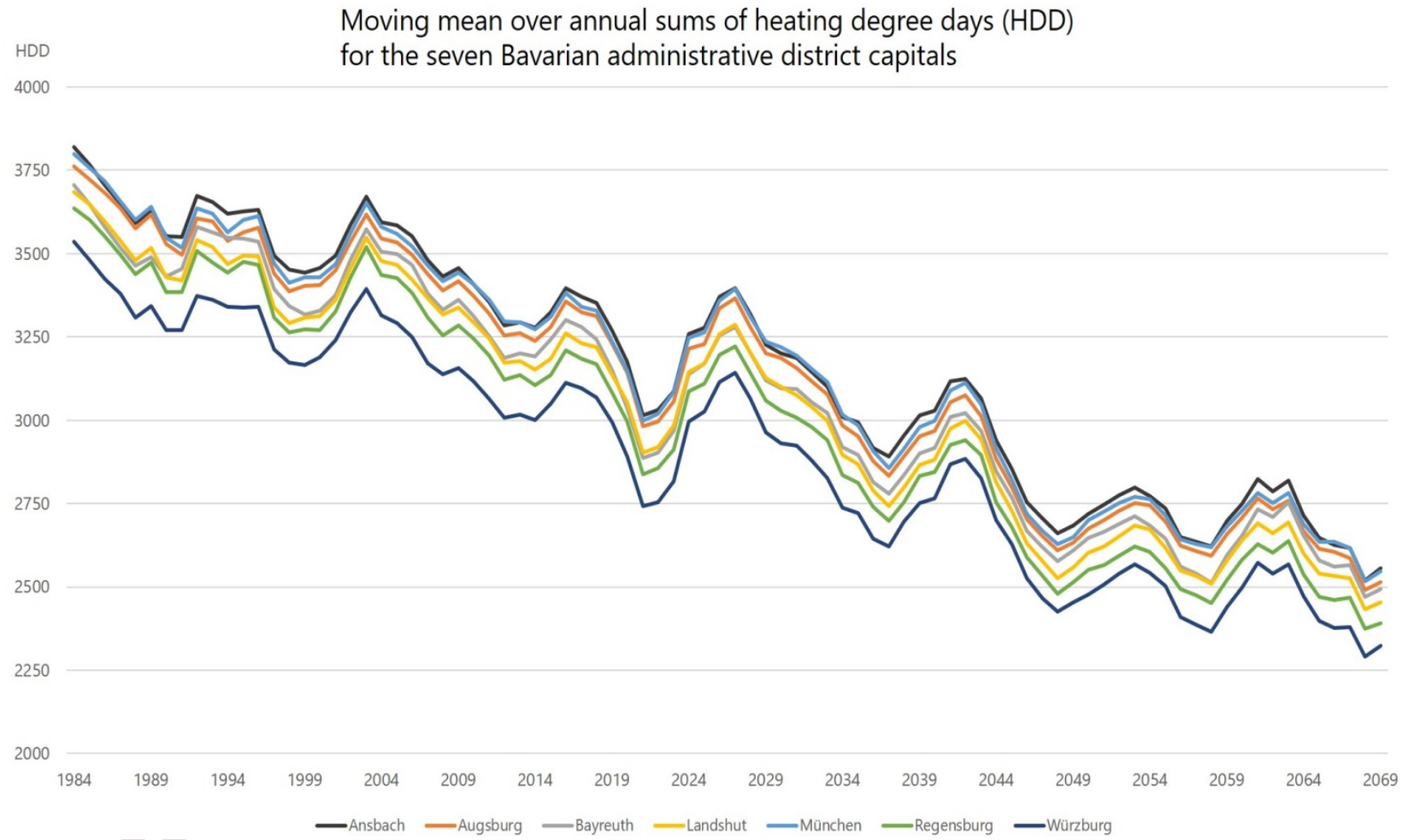
Impacts of climate change on energy demand

Heating and Cooling Degree Days … Bavaria (end of 21st century)

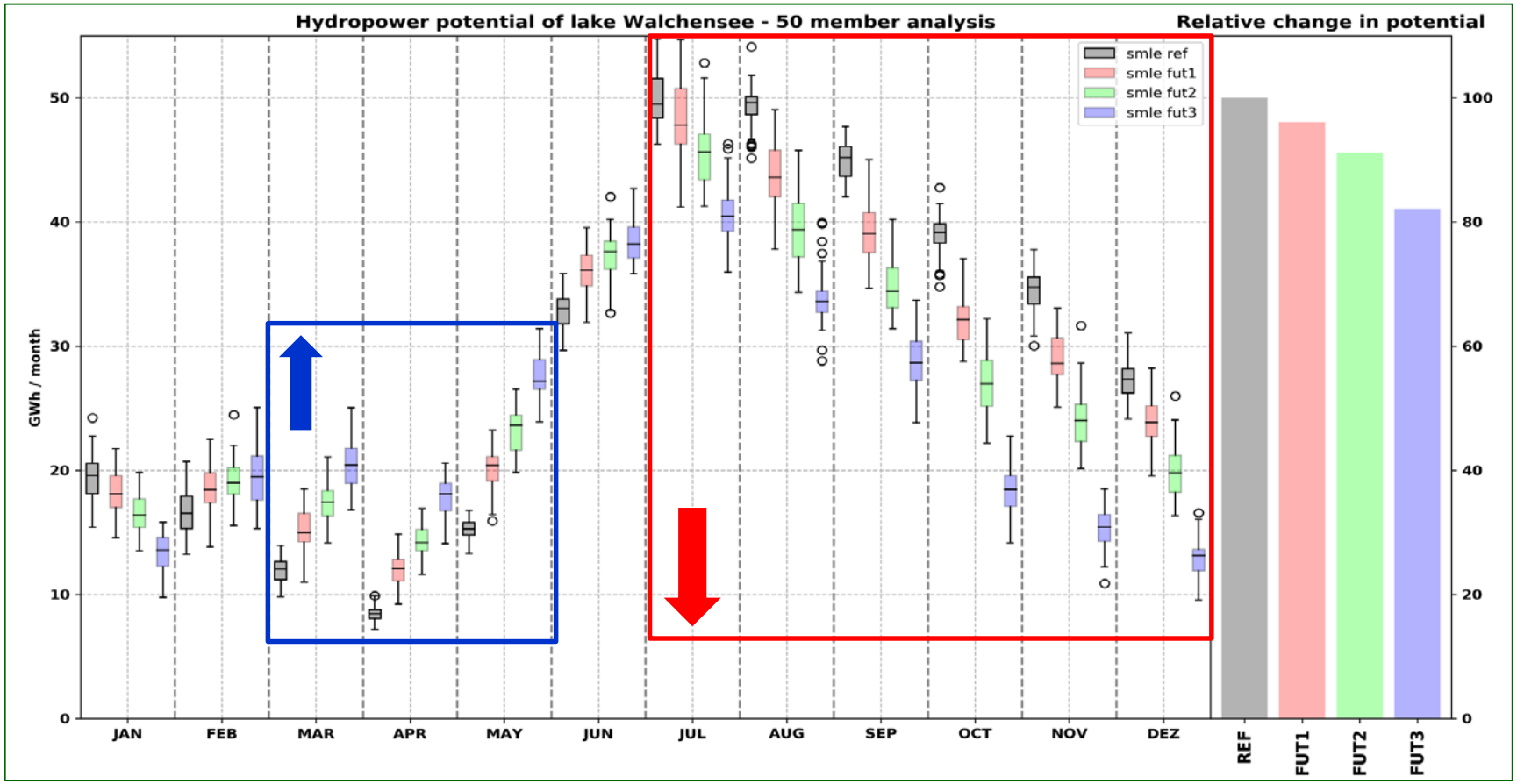


(© Philipp Bauer)

Impacts of climate change on energy supply

An example of CC implications on hydropower generation in Bavaria

Walchensee-Kraftwerk (124 MW)



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ClimEx results

ClimEx …

- uses data from a sensitive climate model under an extreme climate change scenario and shows:
  - very strong increase in temperature, particularly in summer → increased risk for heat waves → strong increase of cooling demand / even stronger decline of heating demand
  - strong increase in winter precipitation → floods
  - strong decrease in summer precipitation → droughts → strong impact on biomass
  - reduced mean annual flow / strong increase in flood risk → strong impact on hydropower
    - Strong implications for multiple domains (agriculture, forestry, water, energy, health…)
- ClimEx-II (09/2020 – 08/2023):
  Droughts, Low flows / Land use change / Weather patterns

Bavaria 2013

Québec 2017

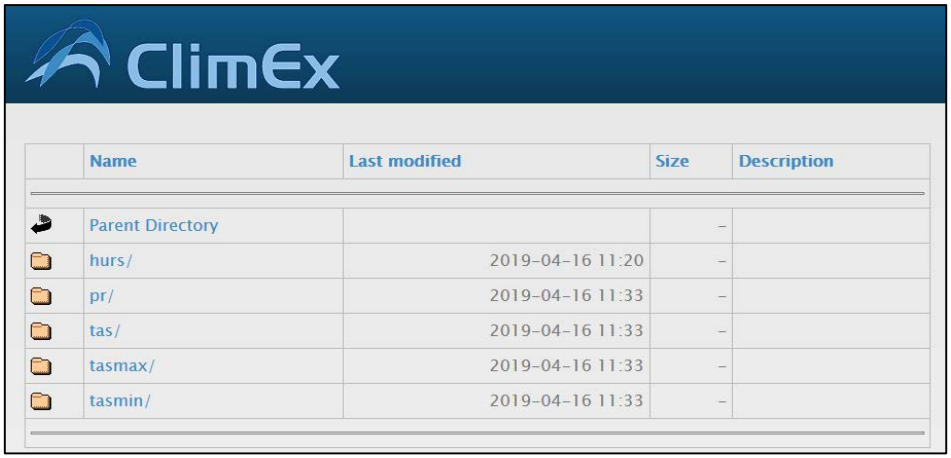
Québec 2019

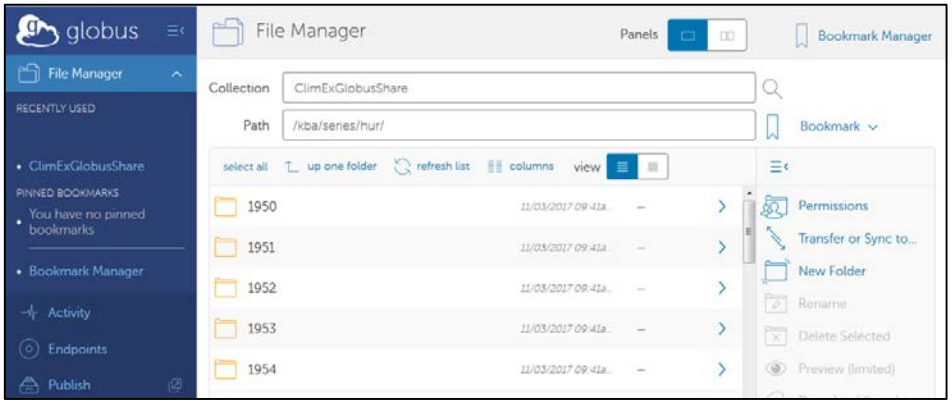
Bavaria 2016

ClimEx – Data policy

Feel free …

www.climex-project.org/en/data-access





Bavaria 2013

Québec 2017

Québec 2019

Bavaria 2016

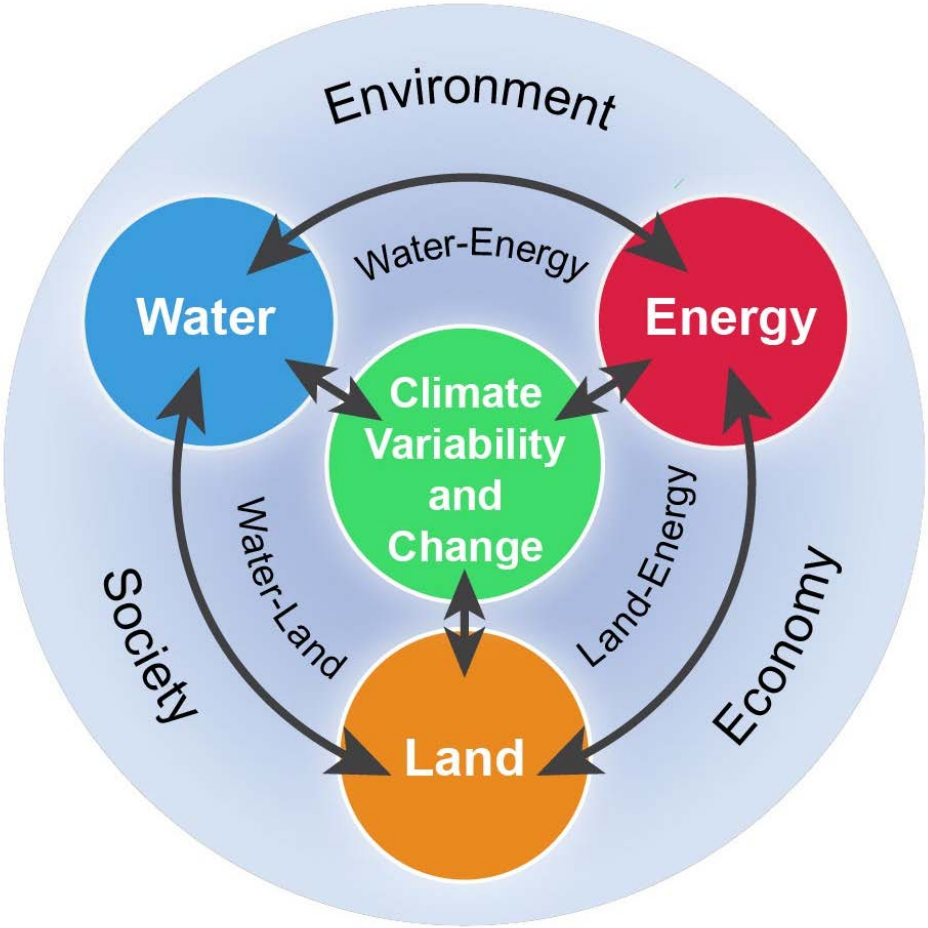
What is there to conclude?

- Reaching ambitious climate mitigation targets requires a rapid and effective transition of energy systems
- Climate change is very likely to have substantial impact on (renewable) energy systems…
  … change seasonal energy demand and supply
  … increase VULNERABILITY and UNCERTAINTY
  … increase COSTS
- Renewable energies must be carefully monitored and managed to reduce/avoid environmental impact

- Innovative, interdisciplinary research is needed to better evaluate the co-evolution of energy systems and ecosystems to foster sustainable development under climate change – a grand opportunity for ABBY-Net!

Thank you!!

Energy Systems and the Environment – a sensitive interface



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