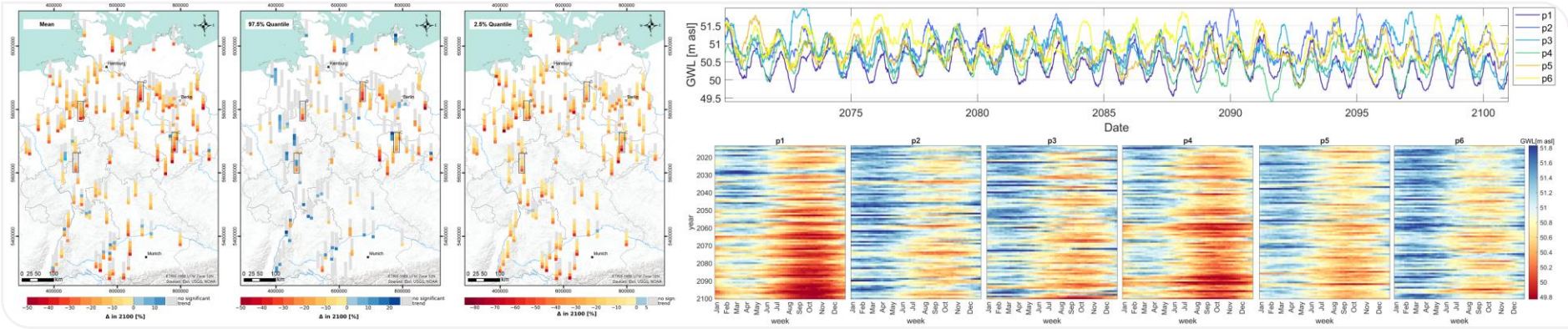
Deep learning shows declining groundwater levels in Germany until 2100 due to climate change

Andreas Wunsch[1], Tanja Liesch[1], Stefan Broda[2]

[1]KIT, [2]BGR



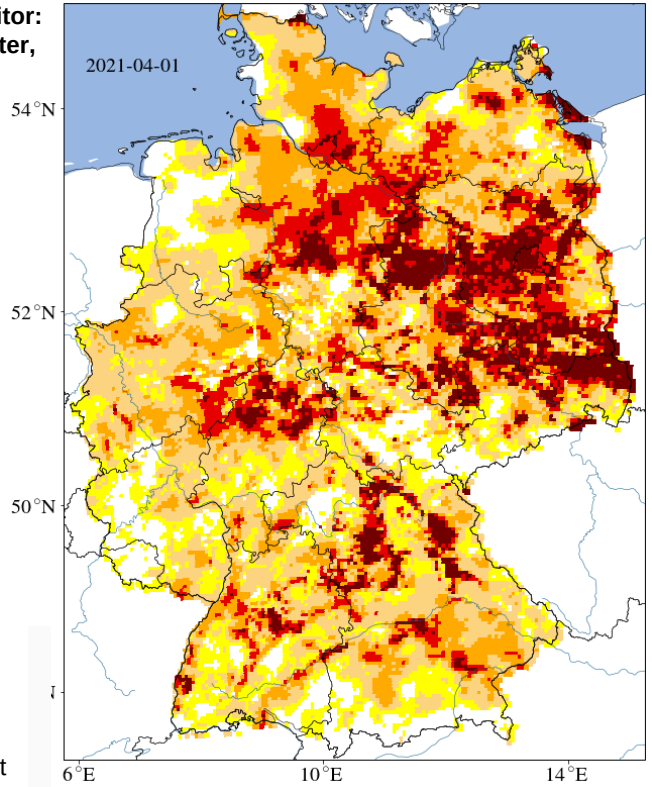
Current Situation in Germany

- Germany is generally water rich[1]
  - water availability per year: 188 billion m³
  - less than 13% are used
- 70% of drinking water supply from GW and springs[2]
- Hot and dry summers in recent years (esp. 2018-2020)

  → ongoing exceptional droughts (few recharge and declining groundwater levels)

  → severe consequences for agriculture and ecology

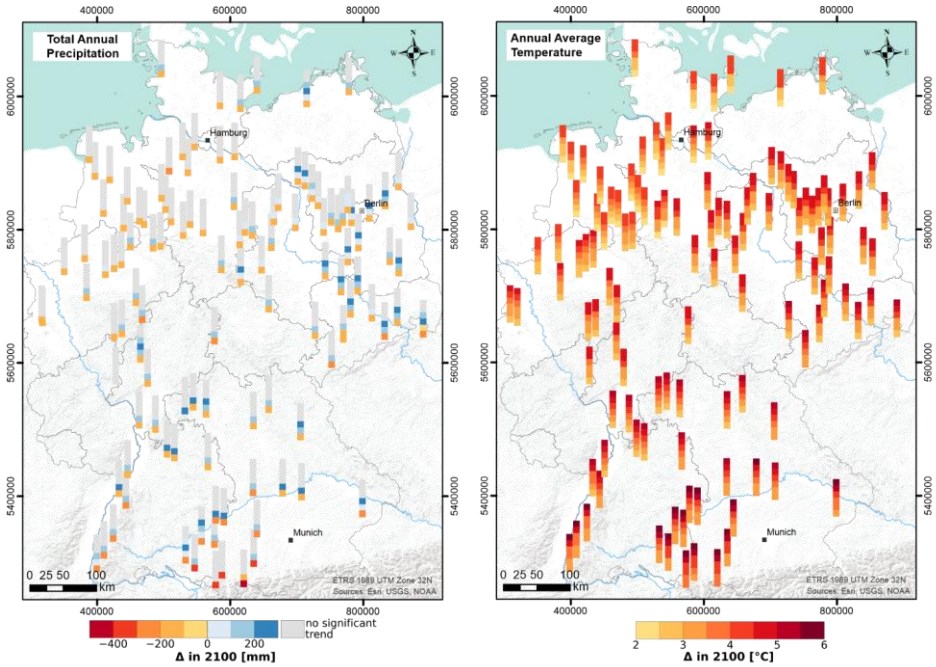
UFZ drought monitor: plant available water, total soil (< 1.8 m) April 2021



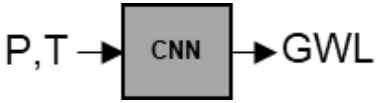
[1] UBA, 2020
[2] DESTATIS, 2016

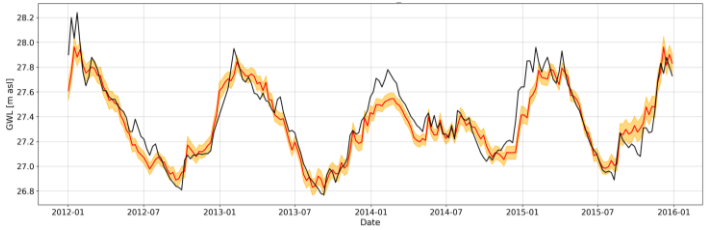
Long-Term Climate

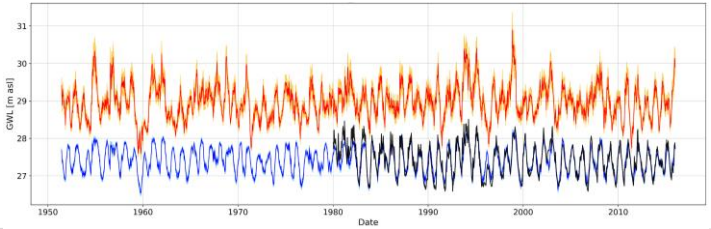
- Simulation of groundwater levels based on climate projection ensemble:
  - 118 sites all over Germany
  - RCP2.6, RCP4.5, **RCP 8.5 (“business as usual”)**
  - 5-6 bias corrected and downscaled projections (5x5 km²) per scenario
  - 80%-90% of total ensemble spread covered by selected models
- Until 2100:
  - Total annual precipitation (left): no trend or slight increase except for one projection
  - Annual avg. Temperature (right): substantial increase



Methods: Model building



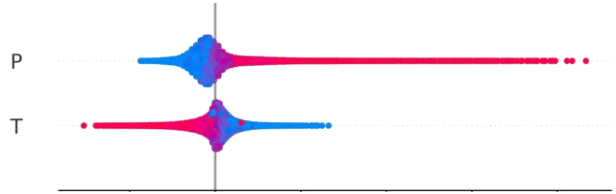




1. Site-specific **1D-CNN Models** to predict GWL using (only) P and T

2. **Train, optimize and validate** Models in the past (observed climate data), select highly performing models

3. **Plausibility checks** (artificial extreme climate scenario (T + 5°C, P x 4) and SHAP values)



Limitations and Assumptions

- Highly Performing Models in the past

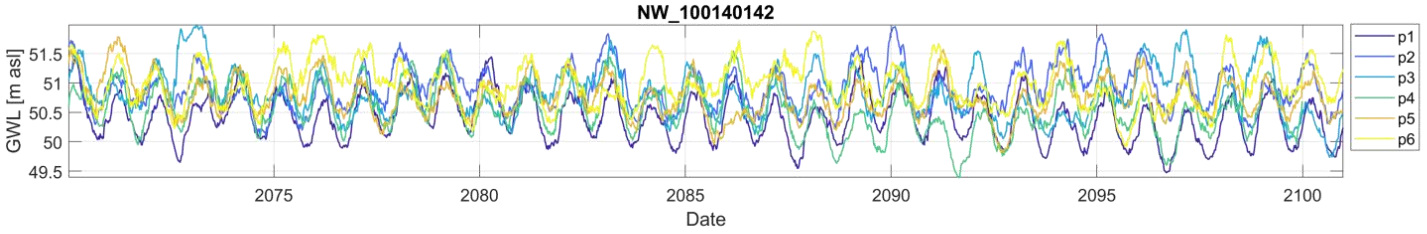
  →sites mainly influenced by climate

- Only climatic influences are taken into account
- Basic input-output relationships remain unchanged

- Secondary, mainly anthropogenic effects are neglected!
- We simulate **direct** climate change effects on GW

Results: Individual Site, 6 different results

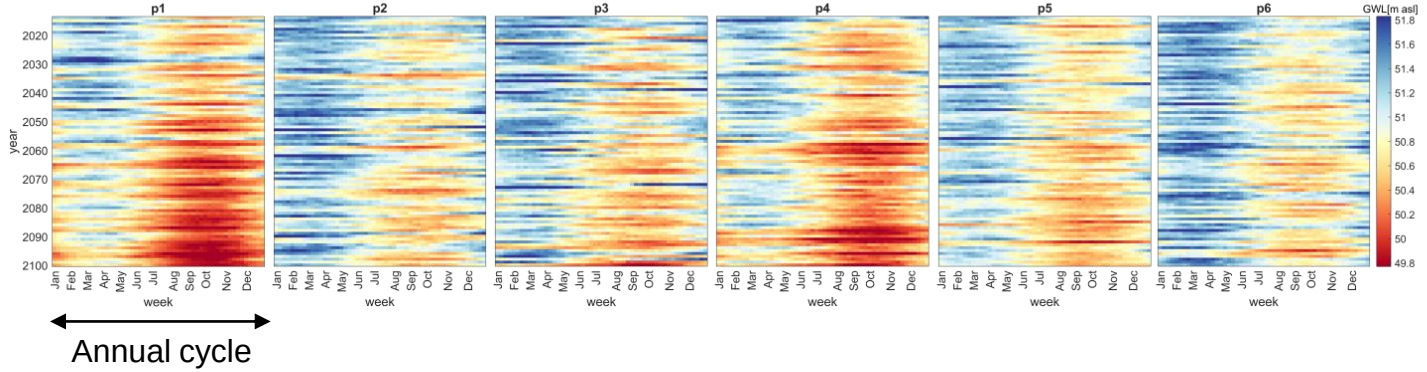
Individual projection results 2070-2100 (partly diverging)



Simulations of complete period as heatmap

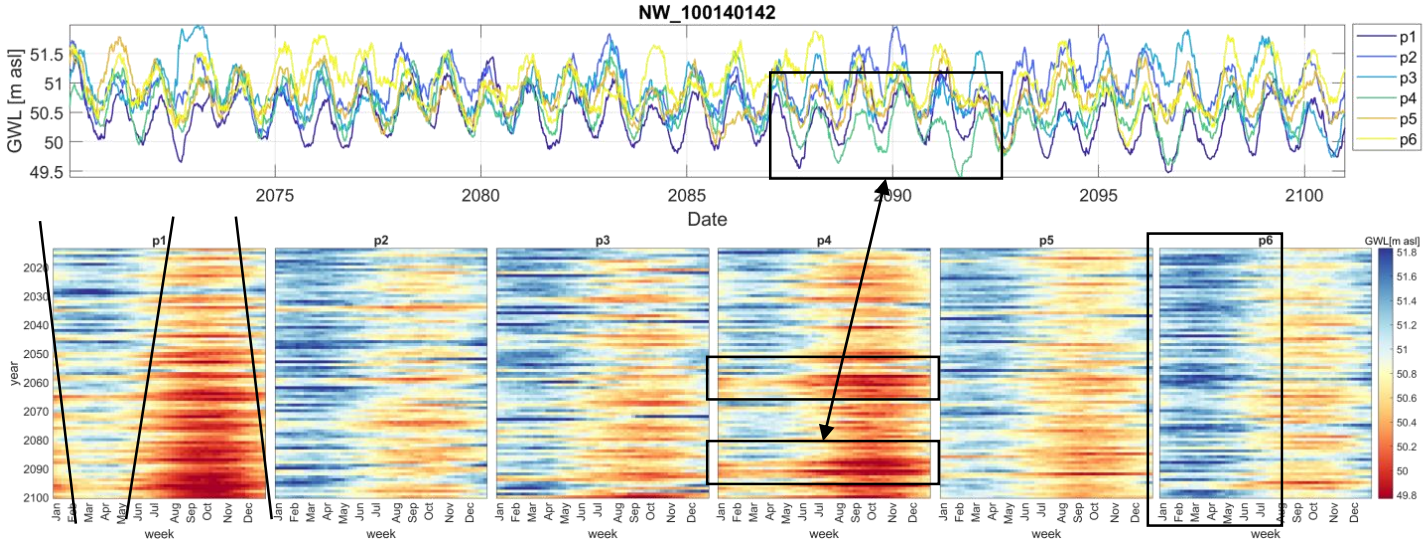
present

future



Annual cycle

Results: Individual Site, 6 different results



Wet periods (blue): shorter and less wet

Dry periods (red): longer and drier

Especially critical:

Succession of several dry years

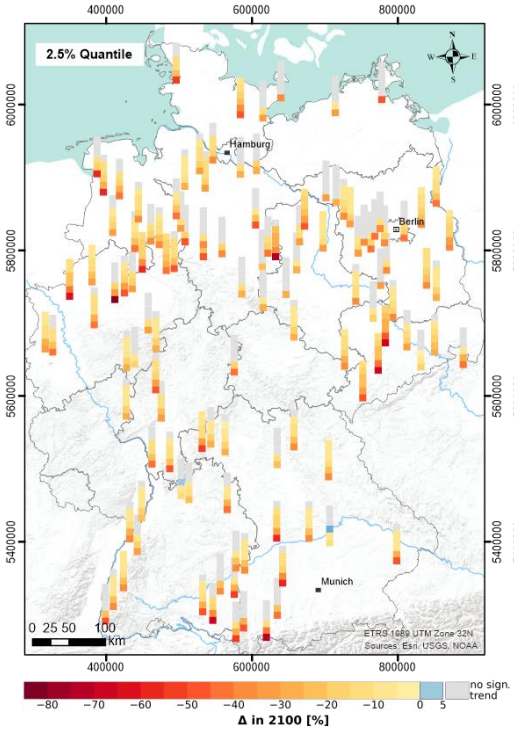
Upper part of annual cycle does not necessarily decrease in absolute height (blue tones remain)

Results: linear trend analyses

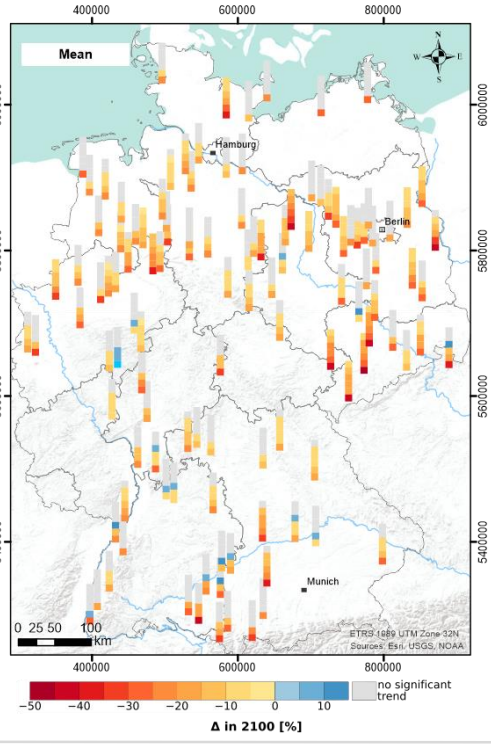
linear trend is based on Mann-Kendall test and Theil-Sen slope

Significant ($p<0.05$) relative changes [%] until 2100 - compared to 2014 (start of sim.) and normalized on individual historic range;

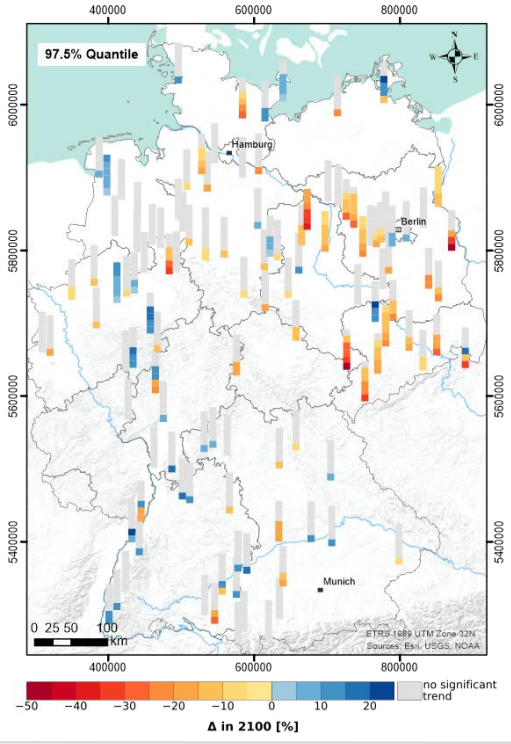
Annual 2.5% quantile



Annual mean



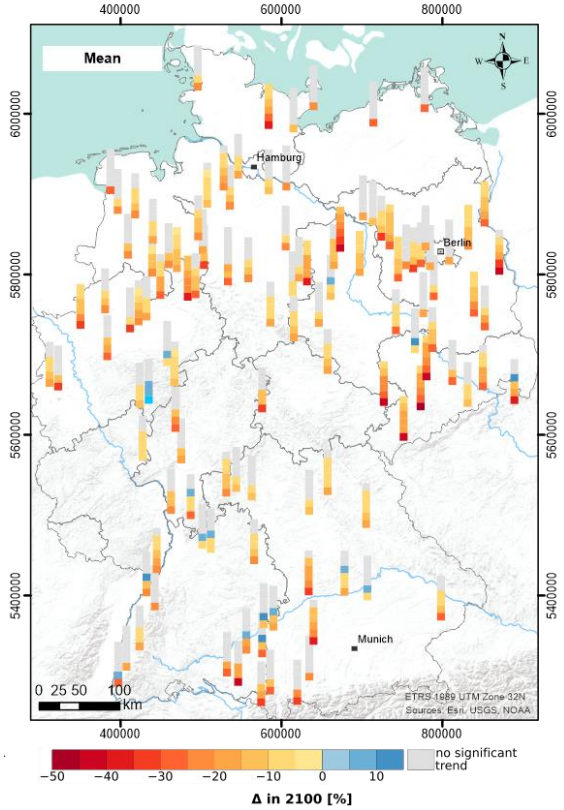
Annual 97.5% quantile

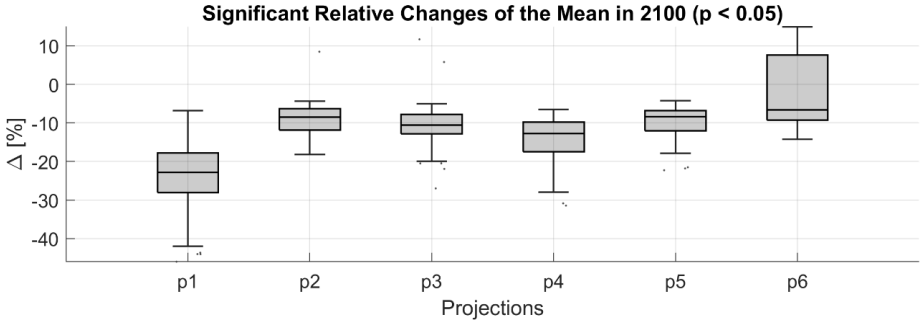


Results: Annual Mean

linear trend is based on Mann-Kendall test and Theil-Sen slope

Significant (p<0.05) relative changes [%] until 2100 - compared to 2014 (start of sim.) and normalized on individual historic range;





- 54% significant trends (p<0.05)
- different developments depending on projection

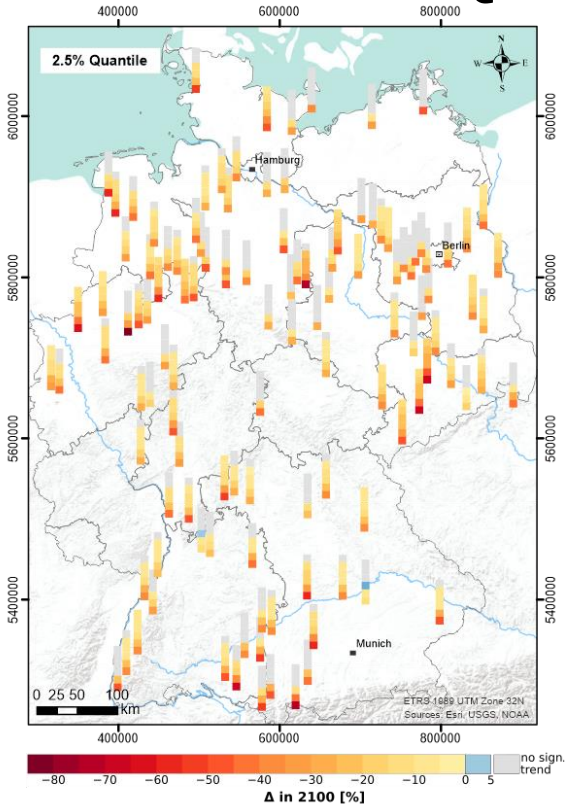
→ median change between -23% (p1) and -6.6% (p6)

→ absolute numbers: -0.1 m to -0.4 m

- more and stronger negative trends in northern and eastern Germany
- some opposite trends at single sites

Results: Annual 2.5% Quantile

linear trend is based on Mann-Kendall test and Theil-Sen slope



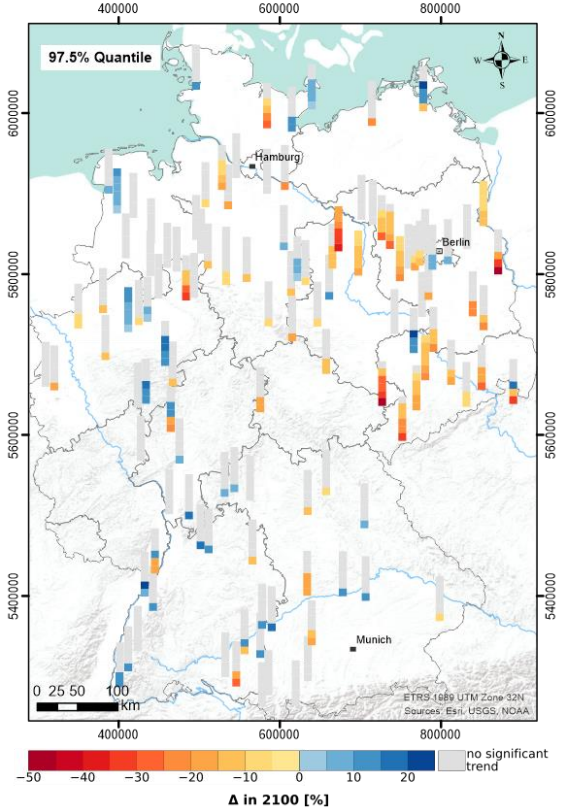
Significant ($p<0.05$) relative changes [%] until 2100 - compared to 2014 (start of sim.) and normalized on individual historic range;

- 64% significant trends
- all but one single result: downward trends
- trends down to -81%
- median changes (depending on the projection) between:
  - → -38% and -10%
  - → absolute: -0.1 m to -0.7 m

Results: Annual 97.5% Quantile

linear trend is based on Mann-Kendall test and Theil-Sen slope

Significant (p<0.05) relative changes [%] until 2100 - compared to 2014 (start of sim.) and normalized on individual historic range;



- >70%: non-significant
- also increasing trends up to 20%
- clear spatial pattern: constant or increasing trends except eastern Germany (declining trends)
- Opposing trends compared to other quantiles → increasing variability

Summary

- Clear tendency of declining groundwater levels until 2100 in Germany
- Emphasized existing trends: stronger declines in eastern Germany
- Absolute values mostly seem small: order of tens of centimeters

  → nevertheless critical

  → amplified by secondary factors (only direct influence projected)
- Only linear trends: obscured patterns of successive dry years, likely to have serious consequences

Preprint:
Andreas Wunsch, Tanja Liesch, Stefan Broda et al. Deep learning shows declining groundwater levels in Germany until 2100 due to climate change, 22 April 2021, PREPRINT (Version 1) available at Research Square
https://doi.org/10.21203/rs.3.rs-420056/v1

Thank you

Find me on:

https://github.com/AndreasWunsch

https://www.linkedin.com/in/andreaswunsch/

https://hydro.agw.kit.edu/21_172.php

https://www.researchgate.net/profile/Andreas-Wunsch

ORCID: 0000-0002-0585-9549

Email: **andreas.wunsch@kit.edu**