Using kilometre-scale regional climate ensembles for local risk assessment and climate adaptation



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RegIKlim
Regionale Informationen zum Klimahandeln

NUKLEUS
Nutzbare lokale Klimainformationen für Deutschland

ISAP
integrative city-regional adaptation strategies

CLIMXTREME
Climate Change and Extreme Events

FONA
Forschung für Nachhaltigkeit

Gefördert durch:

Bundesministerium für Forschung, Technologie und Raumfahrt

Outline

- Kilometre-scale climate ensembles for Germany
- How CPM the ensembles are used for practical applications
- Summary and conclusions

Overview km-scale ensembles for (Southern) Germany



Part
1

Overview km-scale ensemble for Germany

Ensemble	Region	RCM	GCM	Scenario	Periods	Grid-Size
FPS Convection	Southern Germany, Alps, Italy	5	5	CMIP5 rcp85	1996-2005, 2041-2050, 2090-2099	2-4 km
KIT-KLIWA	Southern Germany (~52°N)	1 CCLM	4	CMIP5 rcp85	1971-2100	2.8 km
NUKLEUS	D+	3 REMO, CCLM, ICON-CLM	3	CMIP6 ssp370	1961-1990, GWL+2°C, GWL+3°C*	3 km
UDAG	D-A-CH	1 ICON-CLM	3	CMIP6 ssp370, ssp126	1961-2100	3 km

* 30-year periods

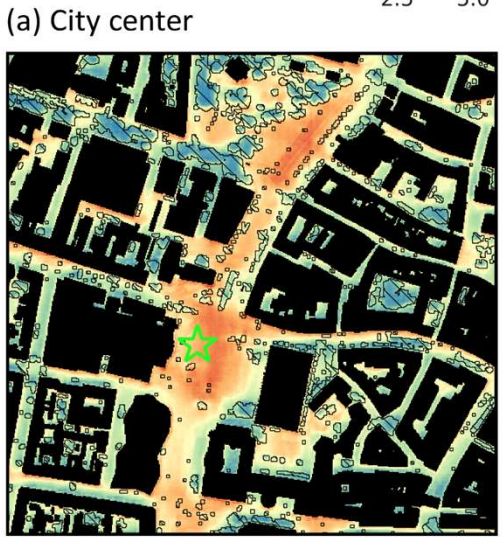
Concept of the existing applications

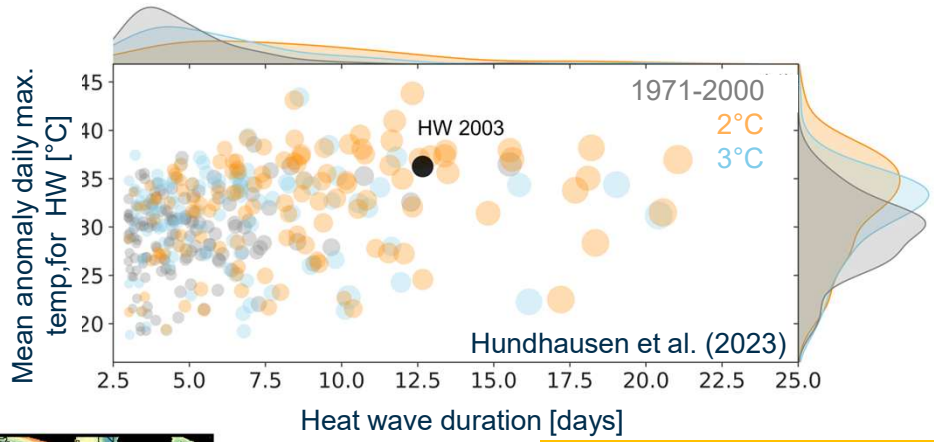
Analysis of hazard risks and their future changes



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Input-data for impact models





Relevant szenarios for Impact studies

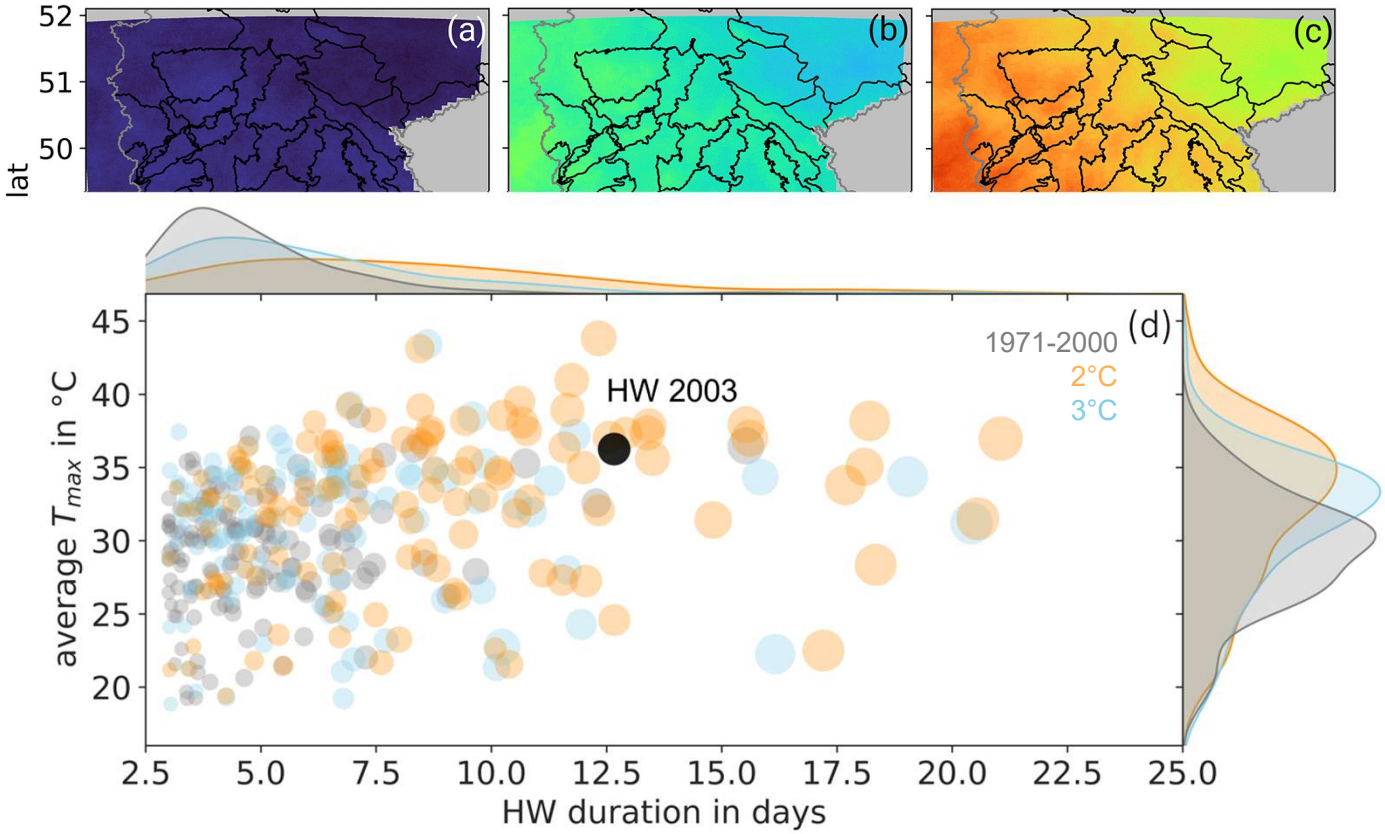
Briegel et al.(2025)

Examples:

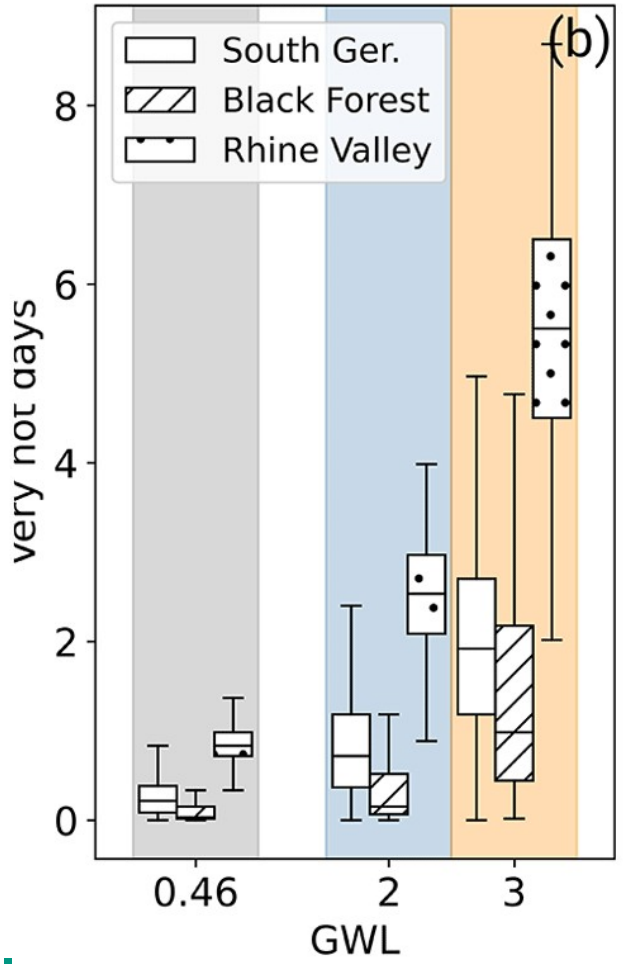
Urban Heat Stress

Climate change information from CPM ensemble analysis

Heat wave days a) 1971.2000; b) GWL2; c) GWL3



Hundhausen et al. (2023)



KIT-KLIWA Ensemble

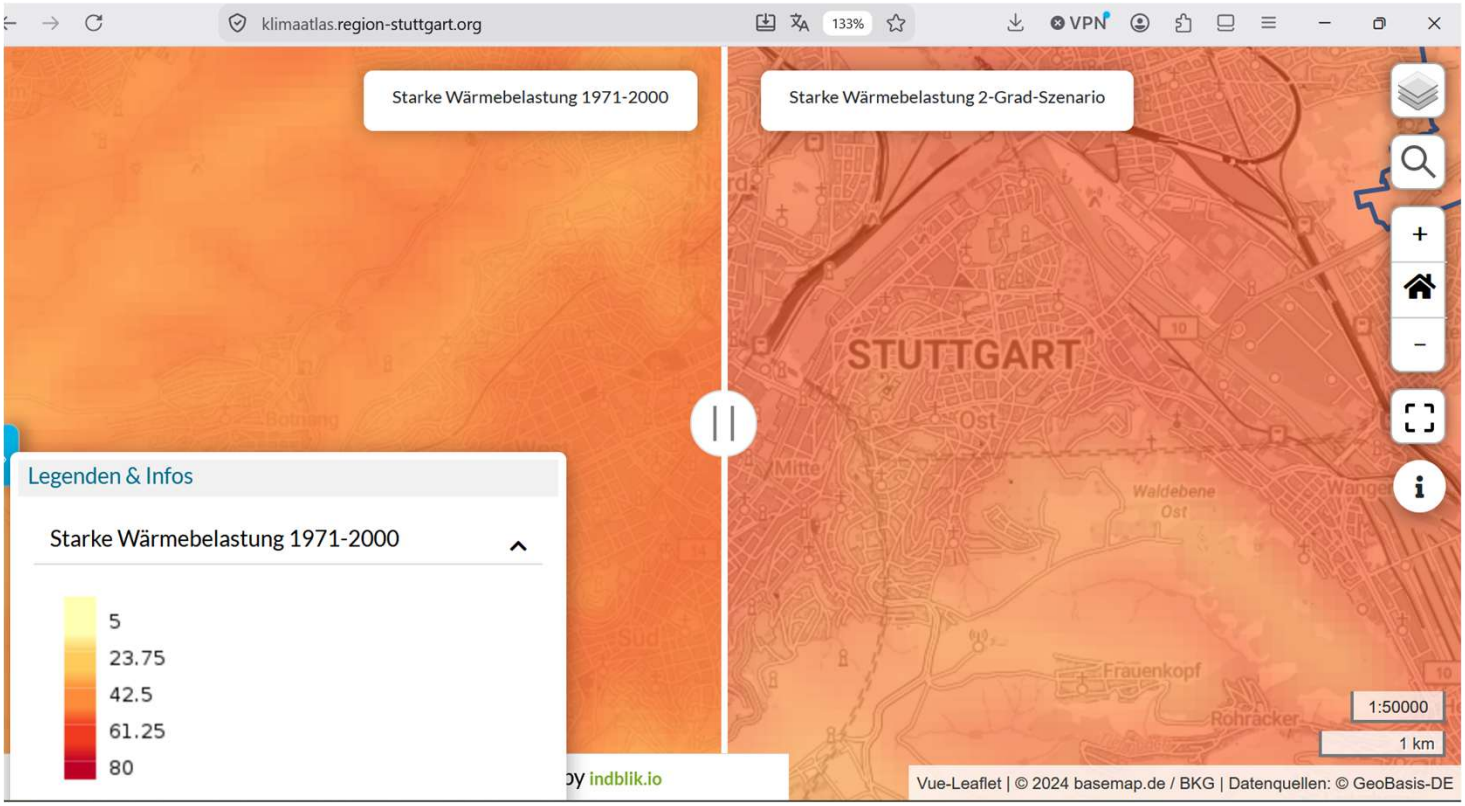
ISAP integrative city-regional adaptation strategies

KIT

Using CPM data for further downscaling

Heat Stress Maps

Days with UTCI > 32°C – Region Stuttgart 1971-2000 vs GWL2



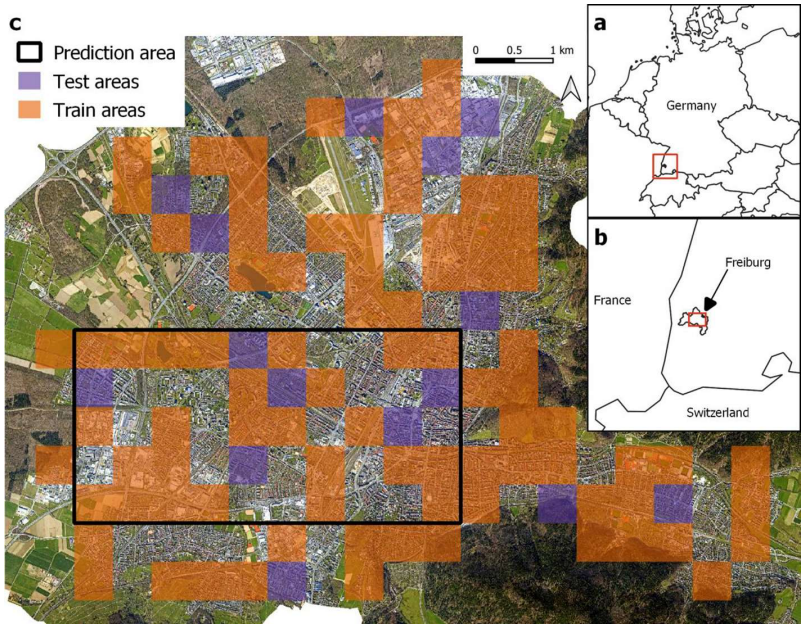
- Downscaling with Palm4U
- 100m resolution
- Performed by Lohmeyer GmbH
- Used for urban planing advice

Can be combined there with exposure and vulnerabilty maps to assess focus areas with priority adaptation needs

https://klimaatlas.region-stuttgart.org/

Combining very high-resolution climate modelling with AI downscaling to street-level scales – Freiburg im Brg.

Urban UTCI future scenarios

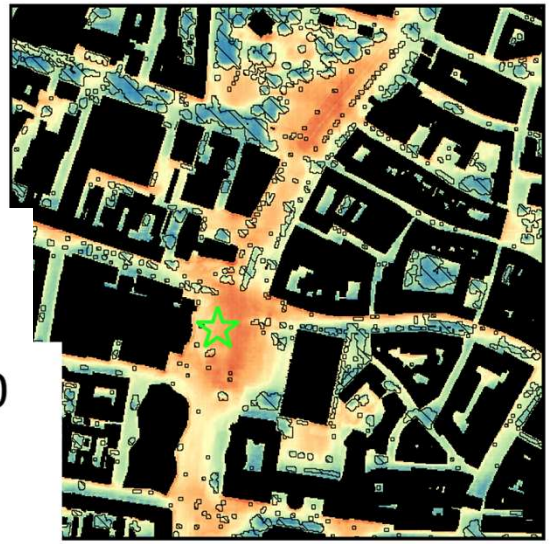


Briegel *et al.* (2025)

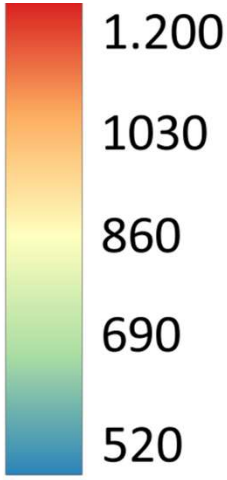
- Study area: Freiburg im Breisgau
- Hgh density city observation network
- Present day climate: ERA5 Land 1990-2019
- Climate change scenarios from RCM/CPM simulations
- Multivariate QDM bias correction
- Variables: tas, RH, air pressure, wind speed and direction, incoming shortwave radiation and incoming longwave radiation
- UHTC-NN UNET model
- training 85 of 100 sub areas from 170 of 200 days, rest for testing
- Application to climate change scenarios 2070-2099

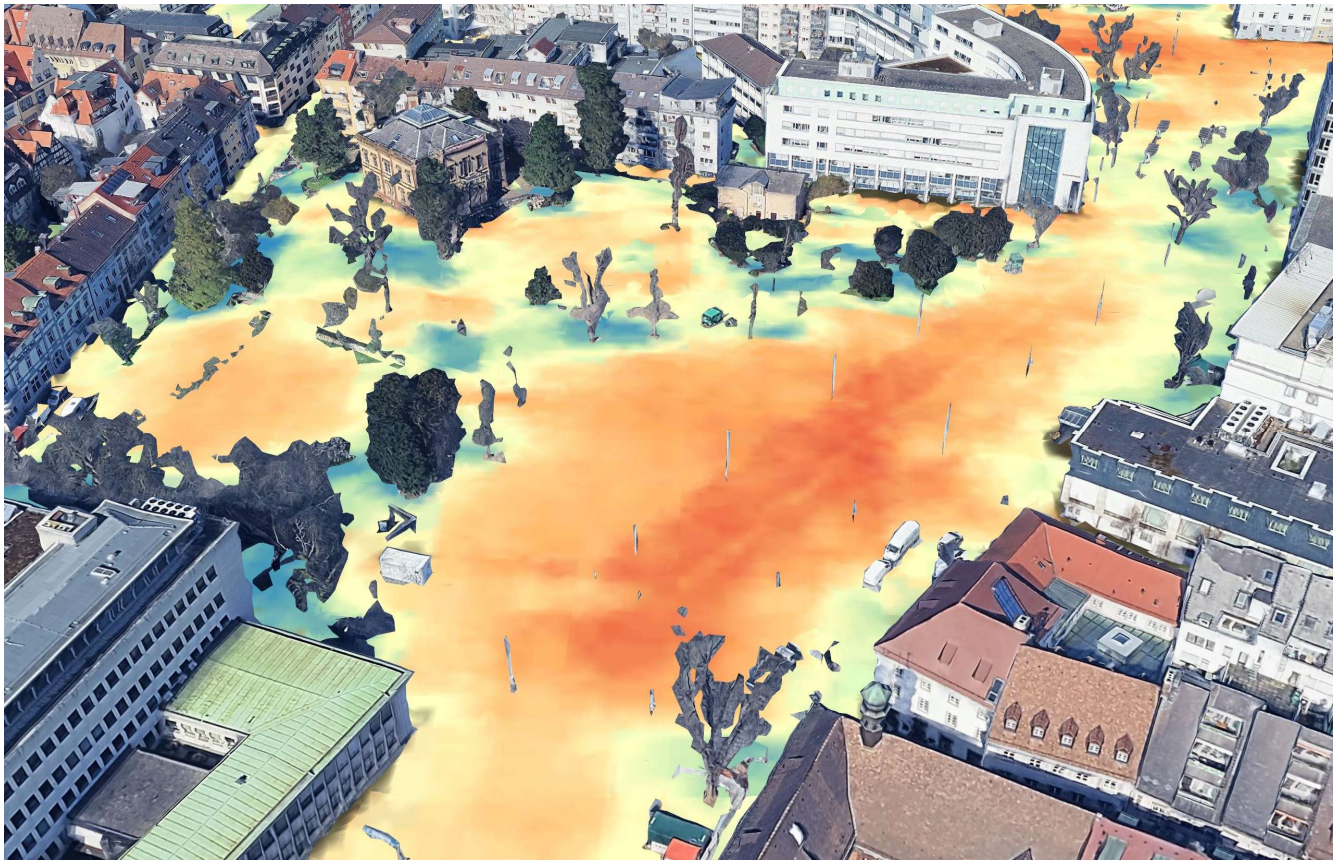
Combining very high-resolution climate modelling with AI downscaling to street-level scales – Freiburg im Brg.

(a) City center



Hitzestress-
stunden
UTCI ≥ 26°C

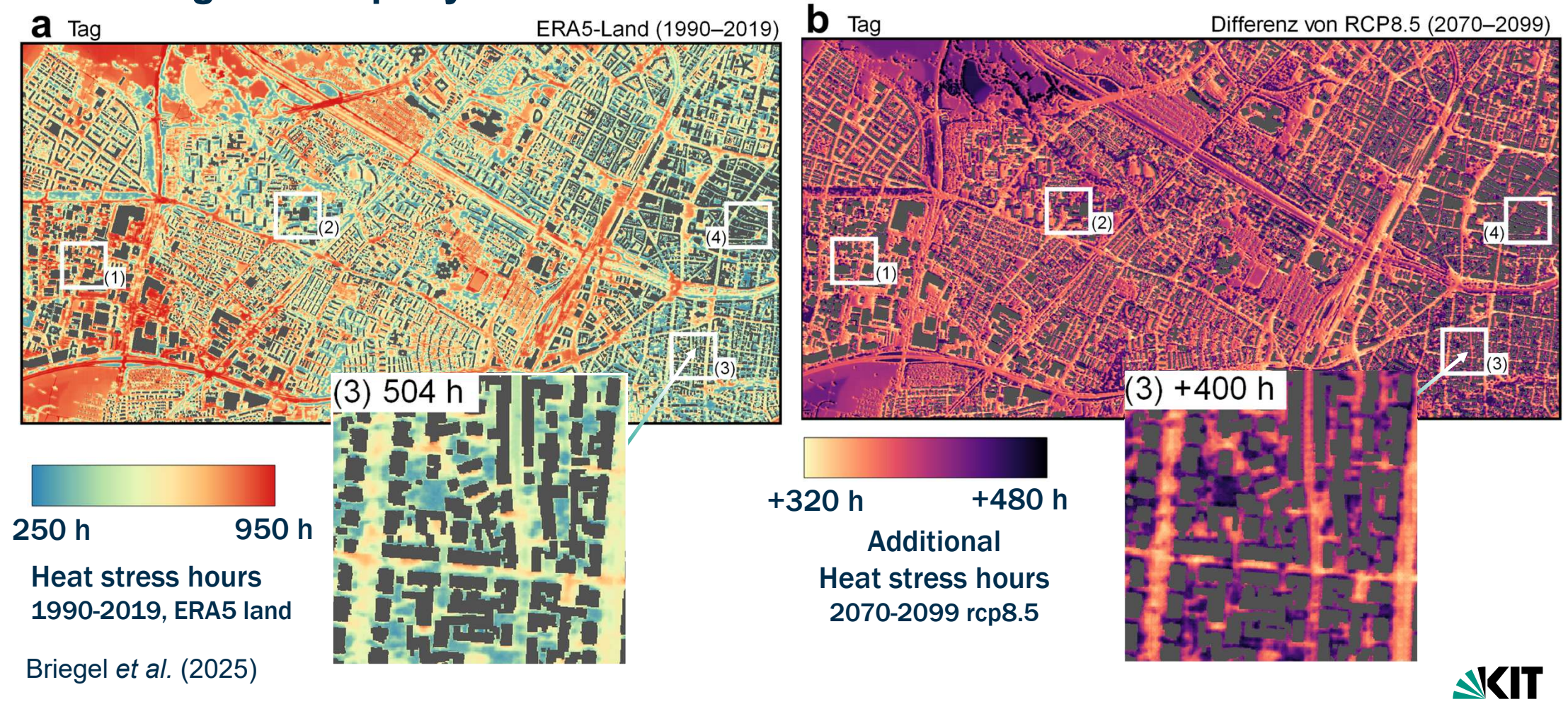




Briegel *et al.* (2025)

AI Downscaling of high-resolution climate simulations

Average hours per year with UTCI ≥ 26 °C → *Heat stress hours*



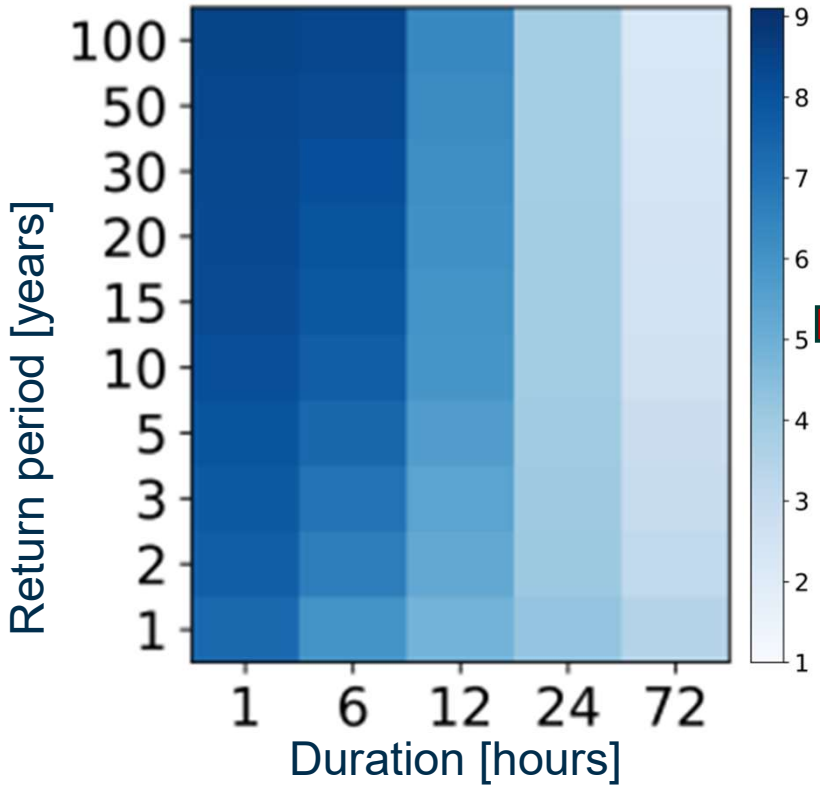
Briegel *et al.* (2025)

Examples:

Extreme Precipitation

Climate change factors extreme precipitation

Change rates [%] extreme precipitation per °C warming



Hundhausen et al. (2024)

Hydrological Modeling



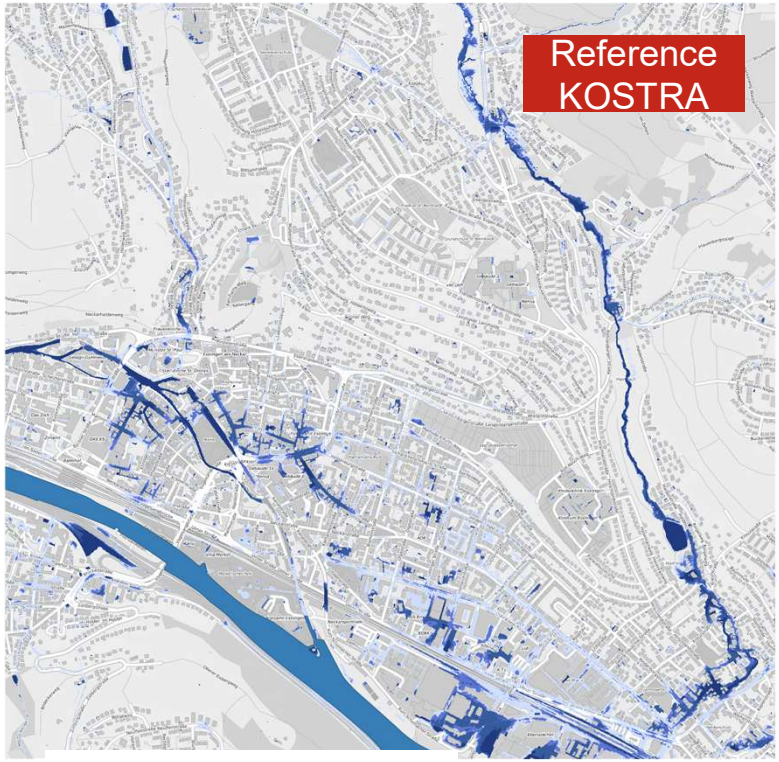
pecher

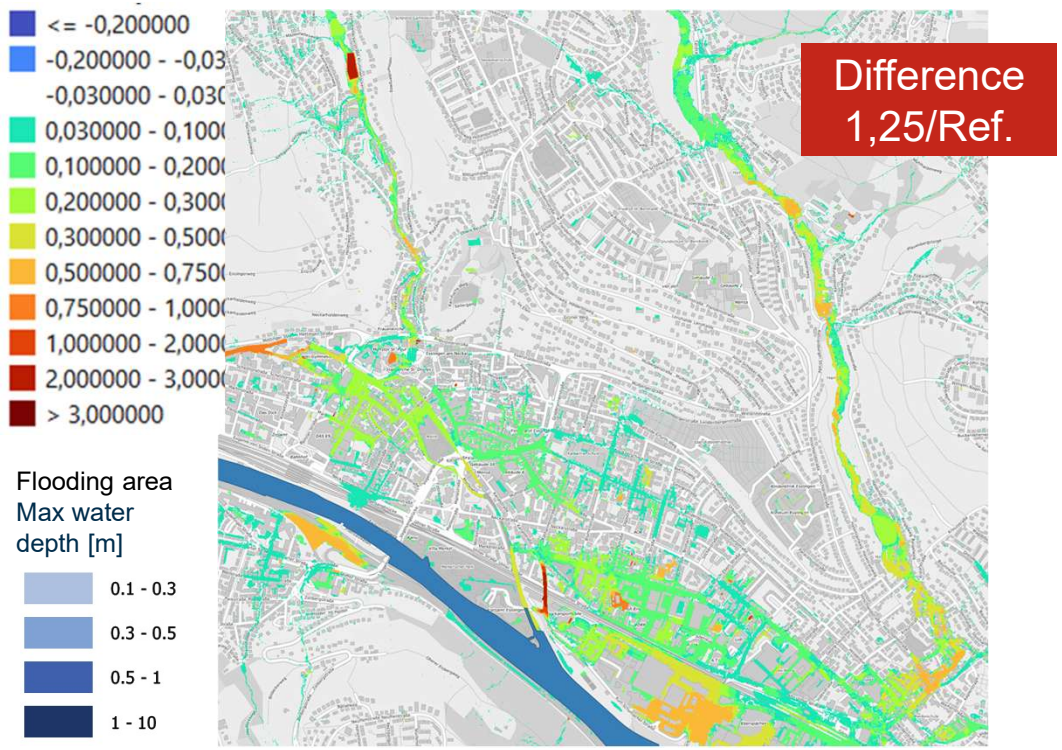
Flood risk map



Application: Klimaatlas Region Stuttgart

Flood-risk map section **Esslingen** for a 30-year event – present day (KOSTRA) and with a climate change factor based on KIT-KLIWA





Background map: © terrestris GmbH und Co., KG (www.terrestris.de/de/demos) / © OpenStreetMap-Mitwirkende (www.openstreetmap.org / www.opendatacommons.org) - 2022

https://klimaatlas.region-stuttgart.org

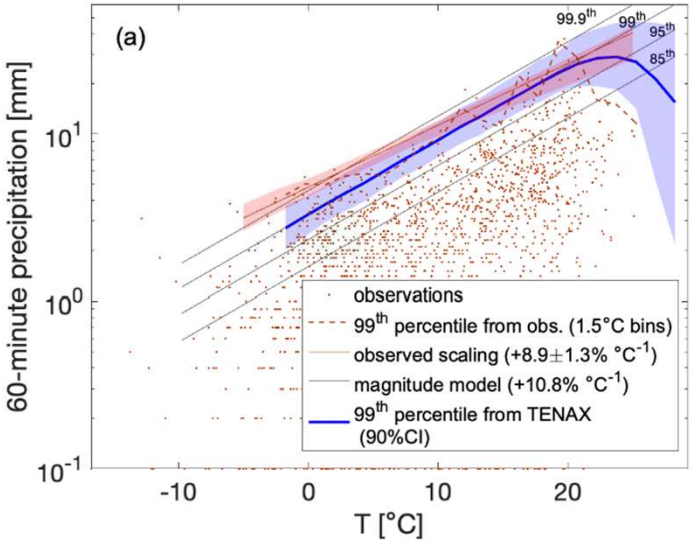
Application: Flood-risk map Weilheim for a 100-year event present day (KOSTRA) and a +2 °C/+3 °C world

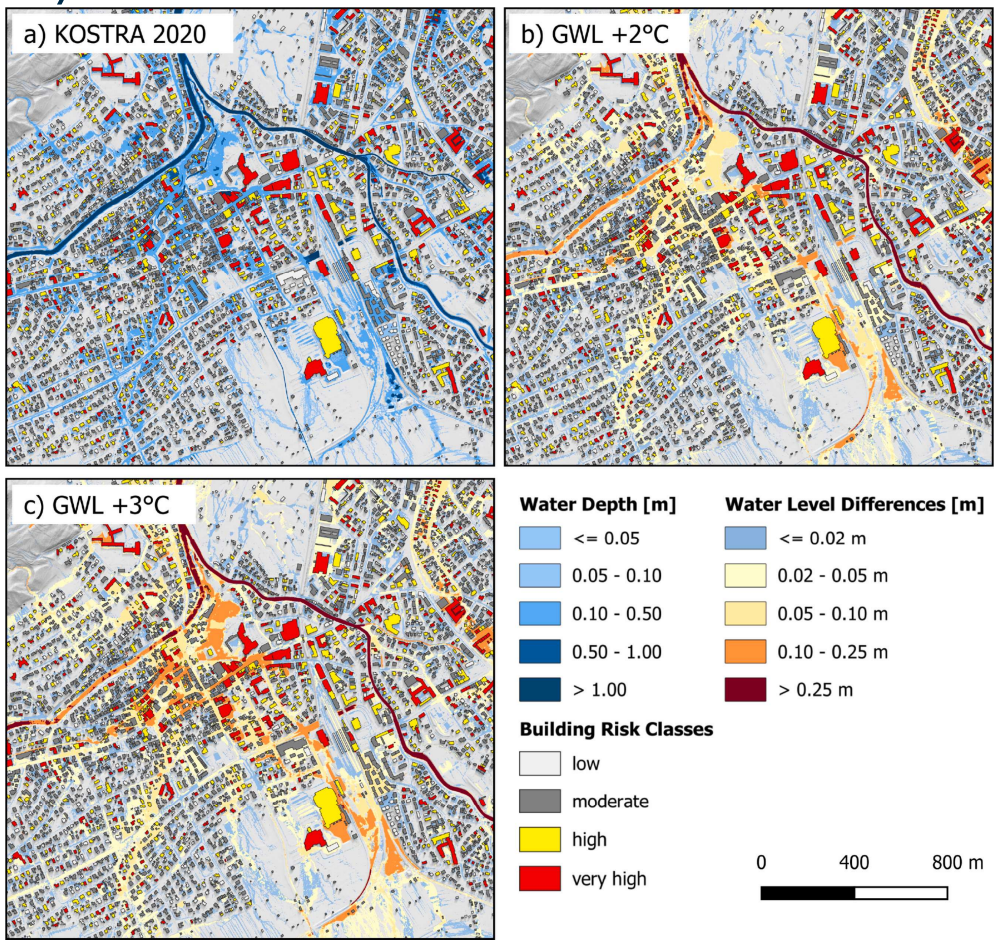
Hydrol. Modelling

Climate scaling with TENAX

using temperature-Data from the

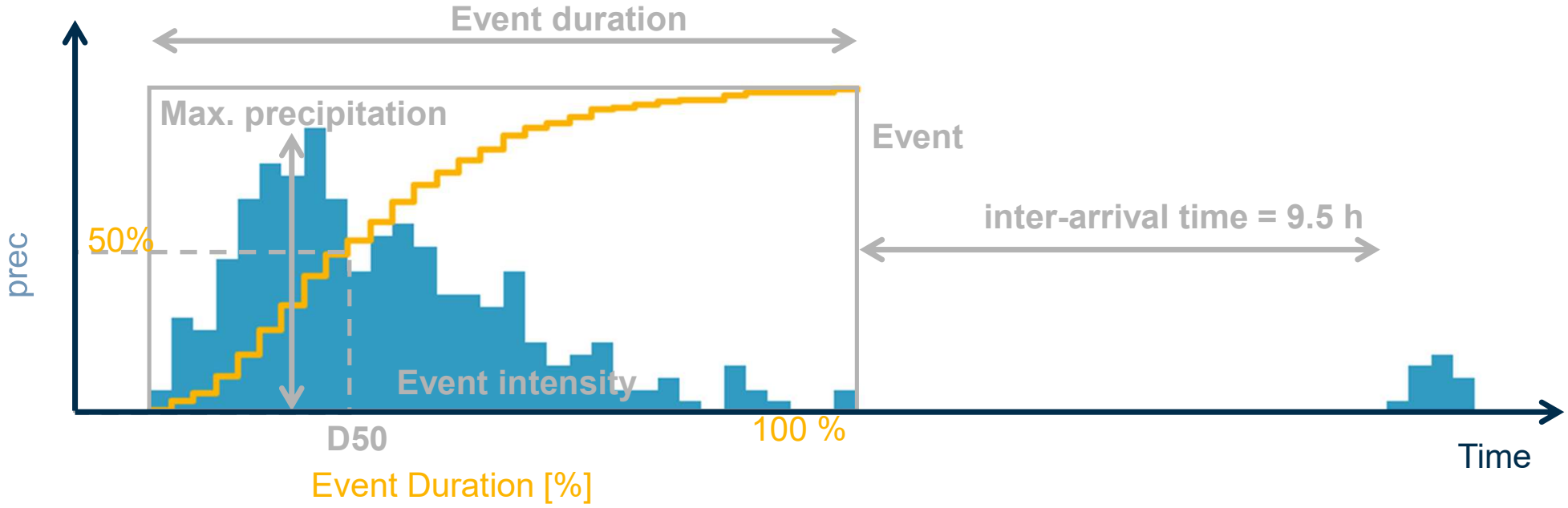
NUKLEUS CPM Ensemble





aus Laux et al., JoH (2025)

Characterizing Extreme Precipitation Events



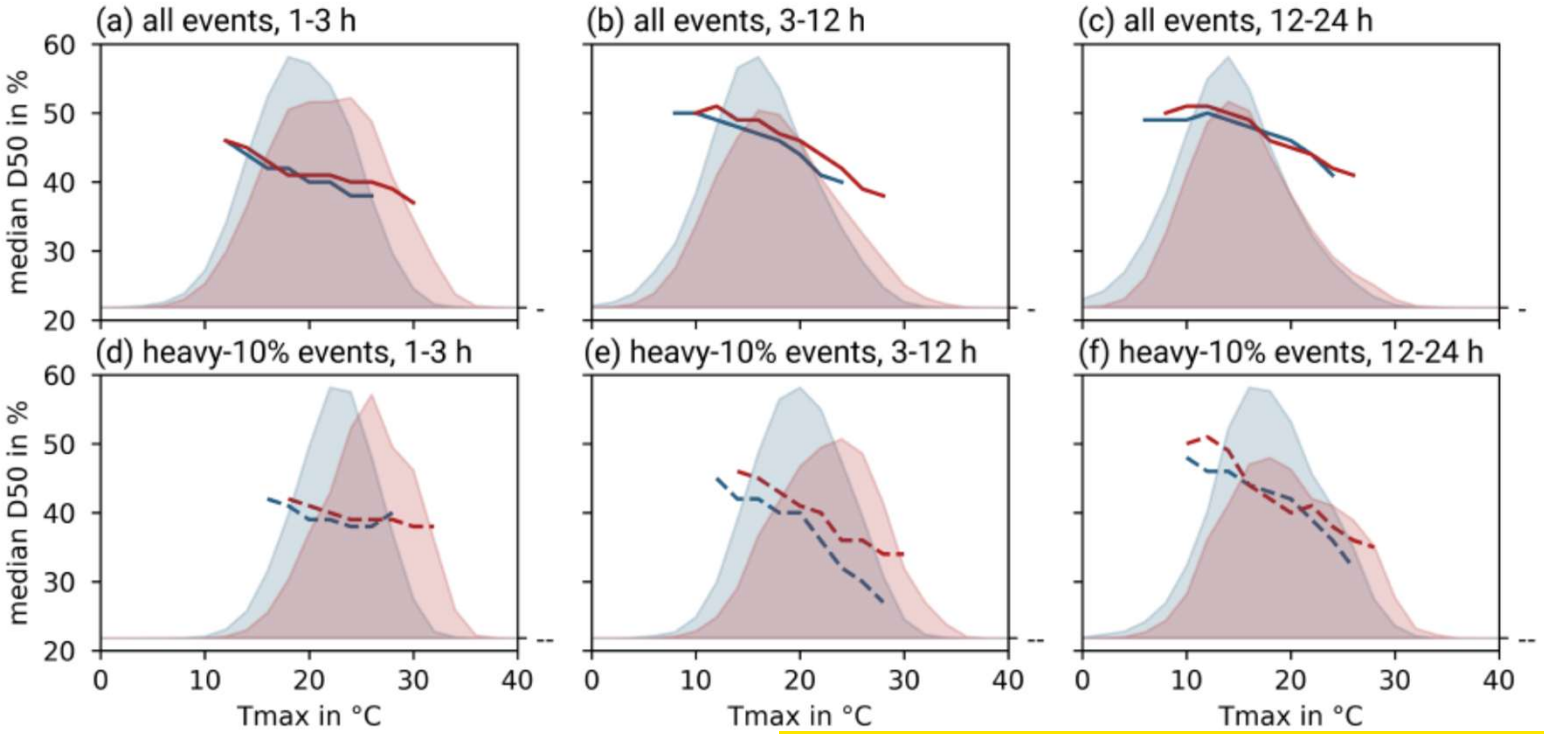
Event Characteristika:

1. Cumulative precipitation amount
2. Peak intensity: Maximum 5min precipitation
3. Event shape: D50 D50 < 50%: front-loaded; > 50% back loaded

Important to define design precipitation

from Hundhausen et al., WACE (2025)

Temporal Evolution of Extreme Precipitation Events (D50) using sub-hourly data – KIT-KLIWA



Under warmer conditions more precipitaion occurs earlier in the event
This is an important information for hydraulic modelling for flood risk maps

from Hundhausen PhD Thesis (2026)

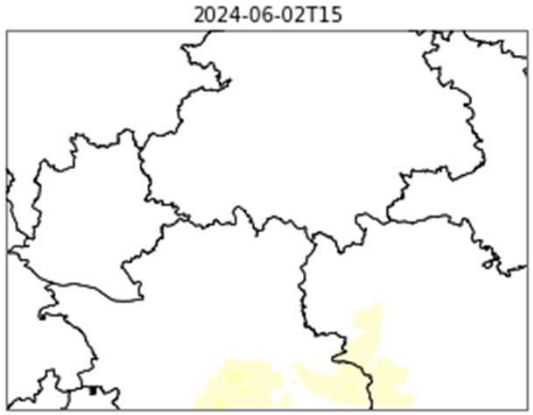
Which flooding depth and flow speeds can be expected? Which uncertainties?

Idealized Experiments – modified observed events (radar-data) to estimate the effects for flood risks with hydraulical models

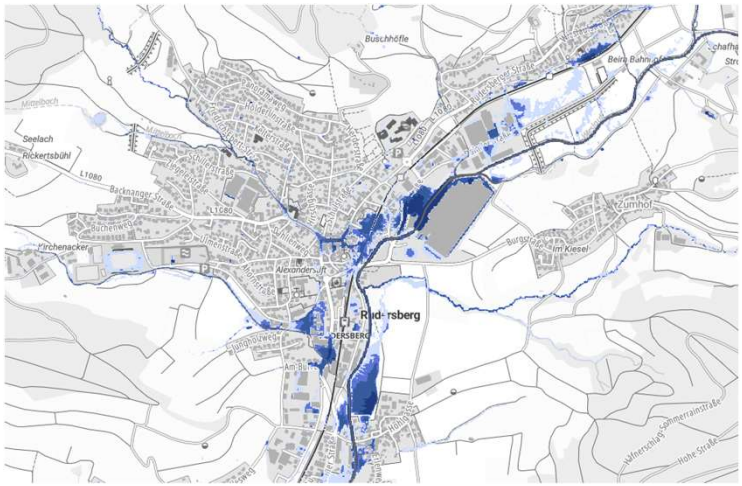
Example: Flash flood in Rudersberg (region Stuttgart) 2024-06-02 (up to 180l)



Rudersberg (Region Stuttgart)



Radar data

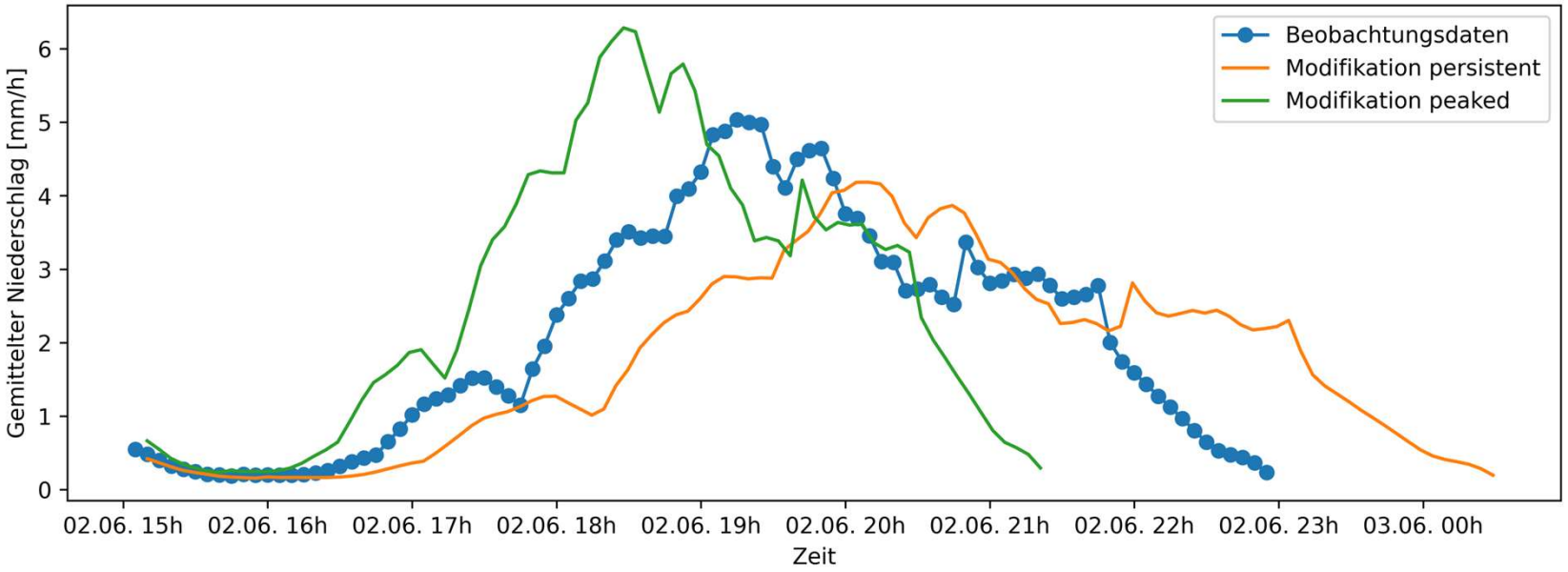


Flood depth in Rudersberg in Rudersberg

pecher

Idealized Experiments – modified observed events (Radar-data) to estimate the effects for flood risks with hydraulical models
radar data, more peaked, front-loaded, more persistent
keeping the total amount constant

Example: Flash flood in Rudersberg (region Stuttgart) 2024-06-02



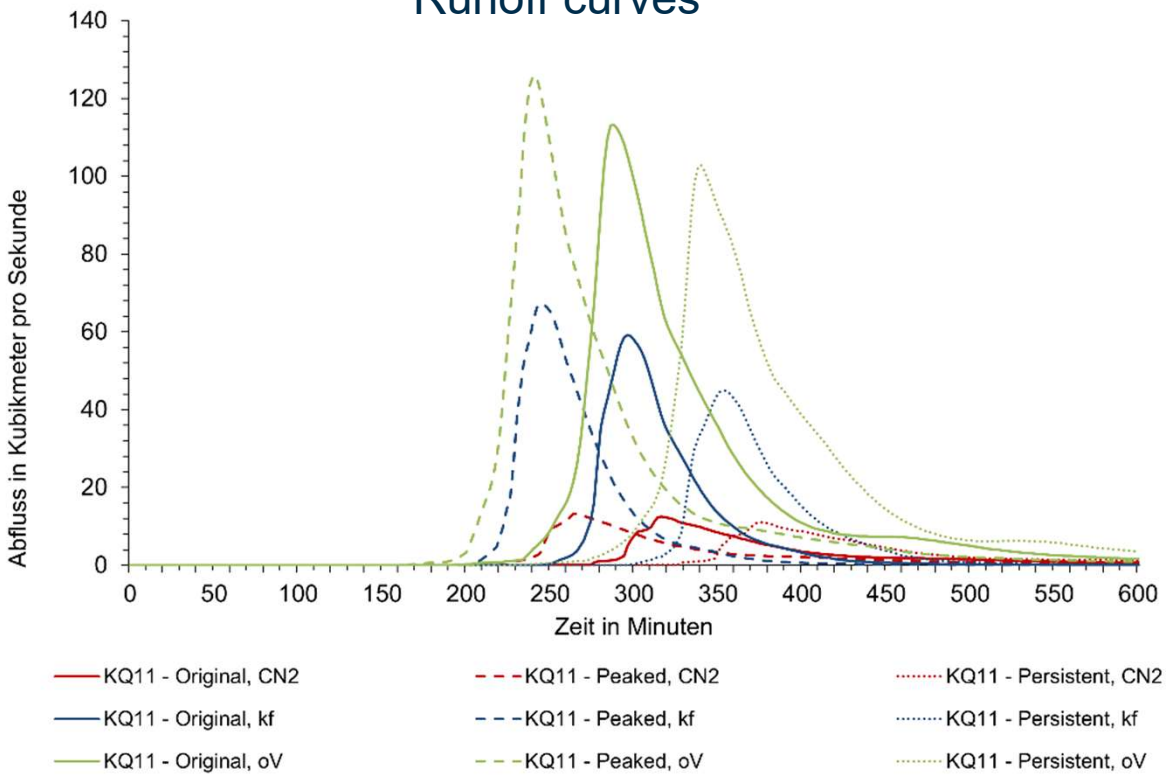
- 2 events
- ref. + 2 mods.
- 5 aproaches
  for runoff generation

30 hydro. Dyn. simulations

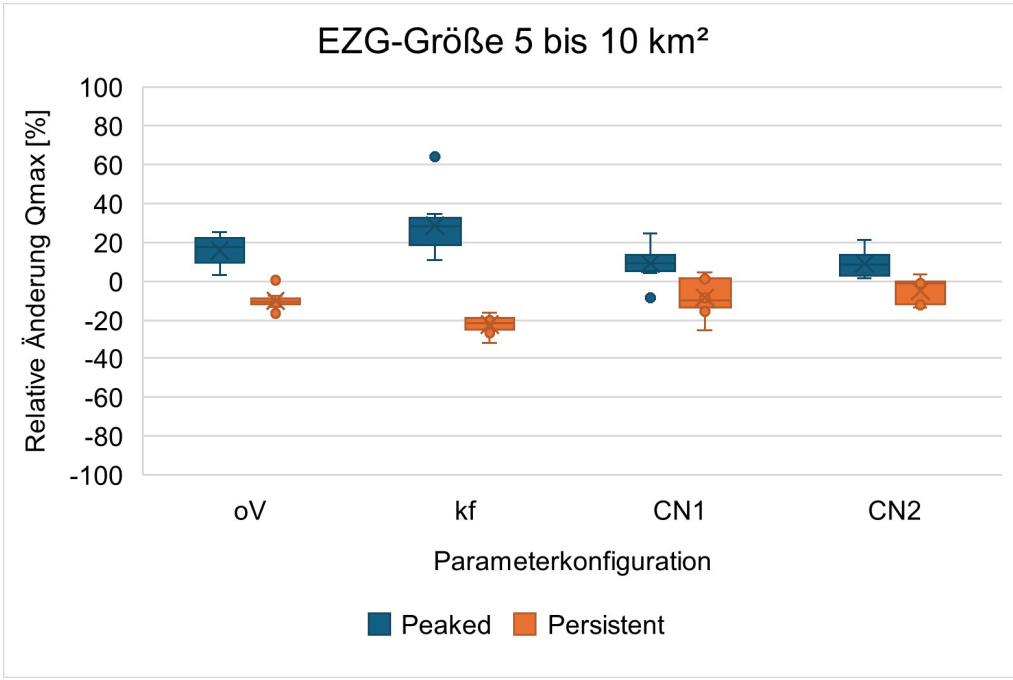
Results of the sensitivity experiments

Example: Flash flood in Rudersberg (region Stuttgart) 2024-06-02

Runoff curves



Max runoff amount Qmax



Summary and Conclusions

Summary and conclusions

- There are already examples where km-scale ensembles are successfully used for communal climate adaptation and risk assessment
- The typical aproach for a successful colaboration includes a joint definition of the information needed for further impact studies or adaptation planning
- The climate simulations can provide
  - Information on hazard risks and their future changes
  - Input data for impact modeling
- Large variability of impact estimates arise from use of different process descriptions in the impact model
- Often there is no sharp criterion, for which climate state and risk level the adaptation should be performed

Thank you for your attention

Referenzen

CORDEX FPS Convection

- **Convection-permitting climate models offer more certain extreme rainfall projections.** 2024, Fosser, G., Gaetani, M., Kendon, E.J, Adinolfi, M., Ban, N., Belušić, D., Caillaud, C., Careto, J.A.M., Coppola, E., Demory, M.-E., de Vries, H., Dobler, A., Feldmann, H., Goergen,K., Lenderink, G., Pichelli, E., Schär, C., Soares. P.M.M, Somot, S., Tölle, M.H., npj Climate and Atmospheric Science, doi: 10.1038/s41612-024-00600-w
- **Mediterranean Heavy Precipitation Events in a warmer climate: robust versus uncertain changes with a large convection-permitting model ensemble,** 2024, Caillaud, C., Somot, S., Douville, H., Alias, A., Bastin, S., Brienen, S., Demory, M.-E., Dobler, A., Feldmann, H., Frisius, T., Goergen, K., Kendon, E.J., Keuler, K., Lenderink, G., Mercogliano, P., Pichelli, E., Soares, P.M.M., Tölle, M.H., de Vries, H., 2024. Geophysical Research Letters, 51, e2023GL105143, DOI:10.1029/2023GL105143

KIT-KLIWA

- **Sub-hourly precipitation and storm event profiles in a convection permitting multi-GCM ensemble**, 2024: Marie Hundhausen, Hayley J. Fowler, Hendrik Feldmann, Joaquim G. Pinto, Weather and Climate Extremes, 48, Art.-Nr.: 100764. doi:10.1016/j.wace.2025.100764
- **Climate change signals of extreme precipitation return levels for Germany in a transient convection-permitting simulation ensemble**, 2024: Hundhausen, M., Feldmann, H. Kohlhepp, R., Pinto, J.G., International Journal of Climatology, 44(5), 1454–1471. https://doi.org/10.1002/joc.8393
- **Southern Germany's 100-year flash flood discharge expected to increase by 30 % under an RCP8.5 climate, 2026**, Voit, P., Hundhausen, M., Seregina, L., Feldmann, H., Ahrens, B., and Heistermann, M.:, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2026-1229, 2026.
- **The Changing Characteristics of Precipitation Extremes in a High-Resolution Climate Model Ensemble.** Dissertation, 2026, Hundhausen, M. 2026, Januar 19. Karlsruher Institut für Technologie (KIT). doi:10.5445/IR/1000189105

NUKLEUS

- **NUKLEUS - A First Kilometre Scale Multi-model Climate Ensemble for Germany: Evaluation, 2026,** Kevin Sieck, Joaquim G. Pinto, Beate Geyer, Klaus Keuler, Christian Beier, Christoph Braun, Florian Ehmele, Hendrik Feldmann, Thomas Frisius, Philipp Heinrich, Marie Hundhausen, Ronny Petrik, and Katja Trachte, GMD, submitted
- **NUKLEUS - A First Convection Permitting Multi-model Ensemble for Germany: Assessment of future changes in temperature and precipitation extremes** Christian Beier, Katrin Ziegler, Heiko Paeth, Joaquim G. Pinto, Kevin Sieck, Lars Buntemeyer, Beate Geyer, Elena Xoplaki Edgar Espitia, Christoph Braun, Florian, Ehmele, Hendrik Feldmann,c Christopher Kadow, Katja Trachte, Journal of Climate, under revision
- **Assessing the Impact of Climate Change on Urban Flooding: Future Precipitation Extremes and Flood Risk Under +2°C and +3°C Scenarios**, 2025, Laux, P., Feldmann, D., Marra, F., Feldmann, H., Kunstmann, H., Trachte, K., Peleg, N., J. of Hydrology, 661, Article no: 133607. doi:10.1016/j.jhydrol.2025.133607.

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