Sub-daily extreme precipitation trends: new insights from combining radar data and convection permitting climate simulations

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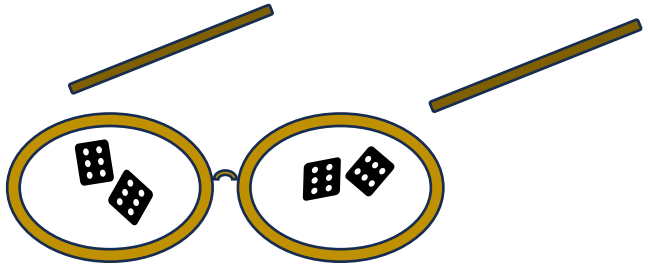
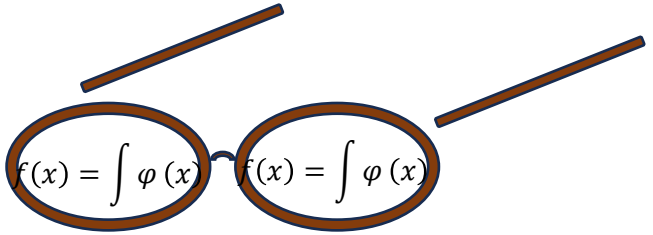
Starting remark

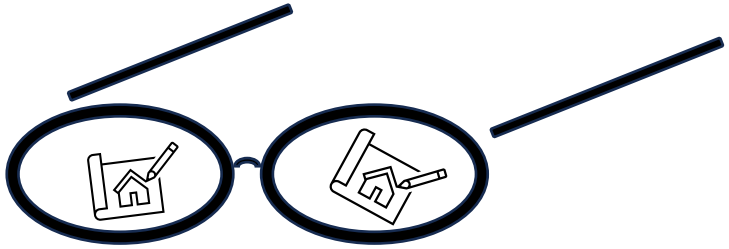
It can be helpful to look at a research question through different lenses:



Statistical



Physical



Engineer

other

Project ZwillE – short overview

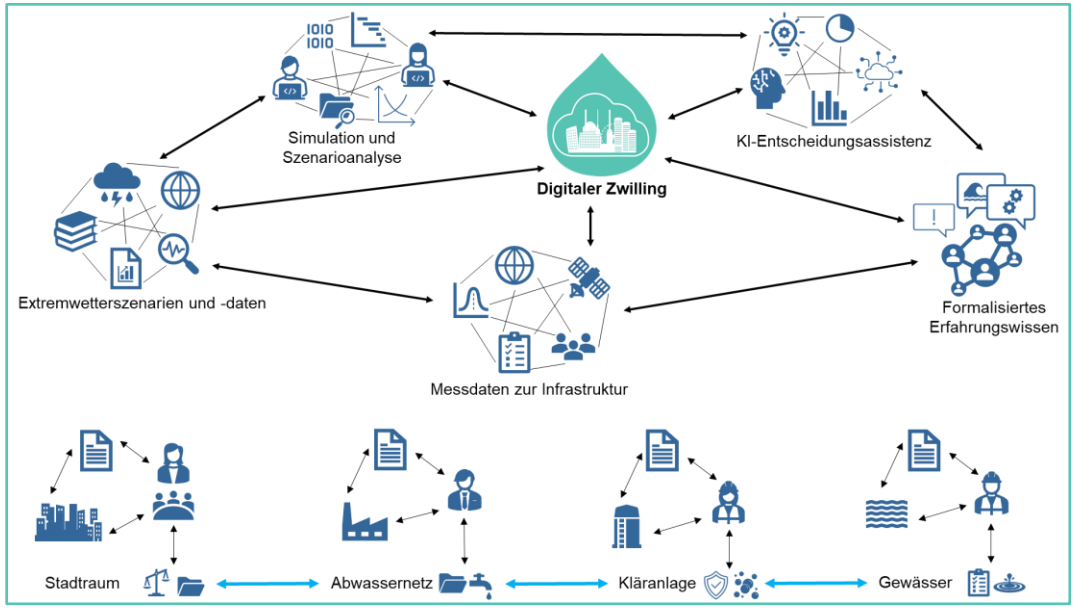
ZwillE is a BMBF funded joint project with 6 project partners.

Study area: City Hanover in Niedersachsen, Germany

Study aim: Development of a **digital twin** for the city (Stadtentwässerung Hannover). Build up a platform which allows for an **integrated view** of the catchments, the water bodies and the drainage system with sewer and waste water treatment plants.

Applications:

1) Current state of the system
2) Short-term measures for managing water extreme events
3) **Measures for long-term adaptation of the drainage system**



Funded by:

Bundesministerium für Bildung und Forschung

FONA Nachhaltiges Wassermanagement

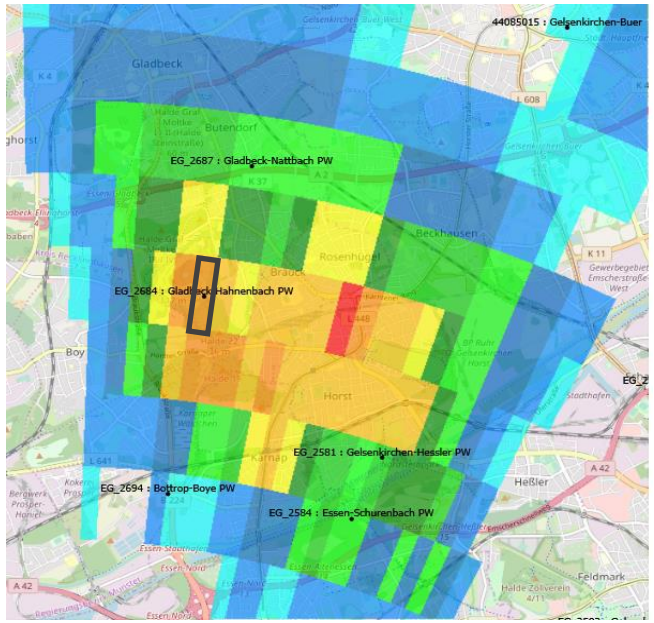
WaX Wasser-Extremereignisse

Observation Data basis - Radar

Available Radar data: 2001-today

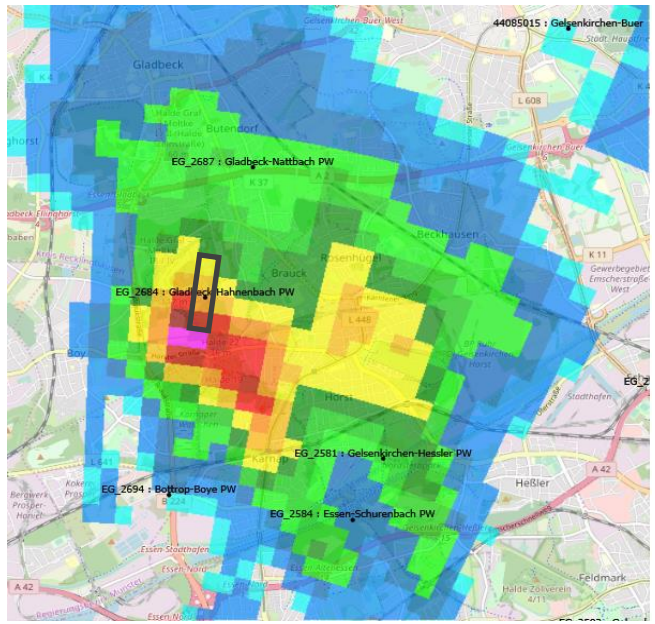
- From the C-Band Radar Hanover (DWD)
- Corrected and adjusted using the software SCOUT (hydro&meteo) and data from rain gauge stations from DWD and SEH (Stadtentwässerung Hannover)

DX polar, 1 km x 1°, 5 min

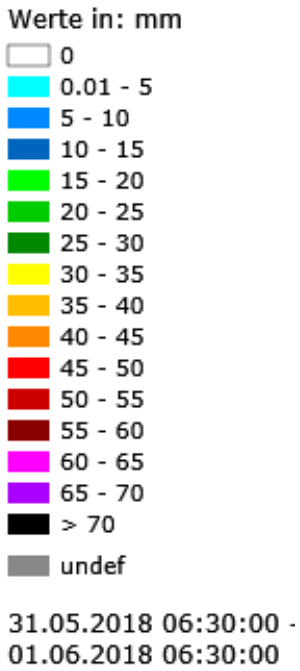


Since 2001

BUFR polar, 250 m x 1°, 5 min



Since 2018



Observed trends of extreme precipitation

What is the observed trend of extreme sub-daily precipitation?

Event-based statistics of extreme precipitation events using the CatRaRE dataset based on RadKLIM (DWD, Lengfeld et al., 2021)

LAWA-Starkregenportal:

- Intersection of CatRaRE event shapes with German Länder shapes
- Filter and visualisation options

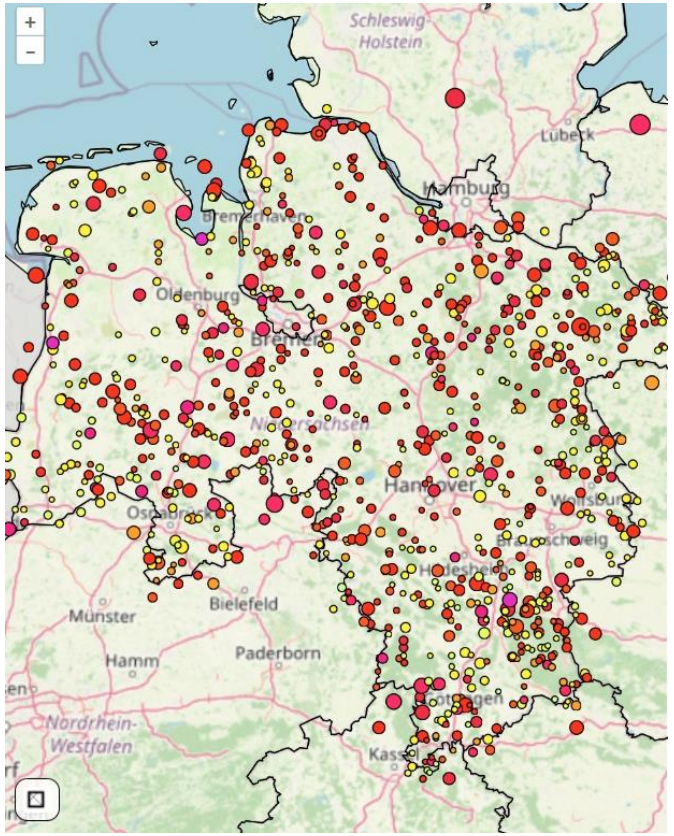
Selected event duration: 60 min – 4 hours:

➔ Number of events in Niedersachsen:

1) 2003-2012: 688 events

2) 2013-2022: 947 events

Relative change: **+ 38 %**



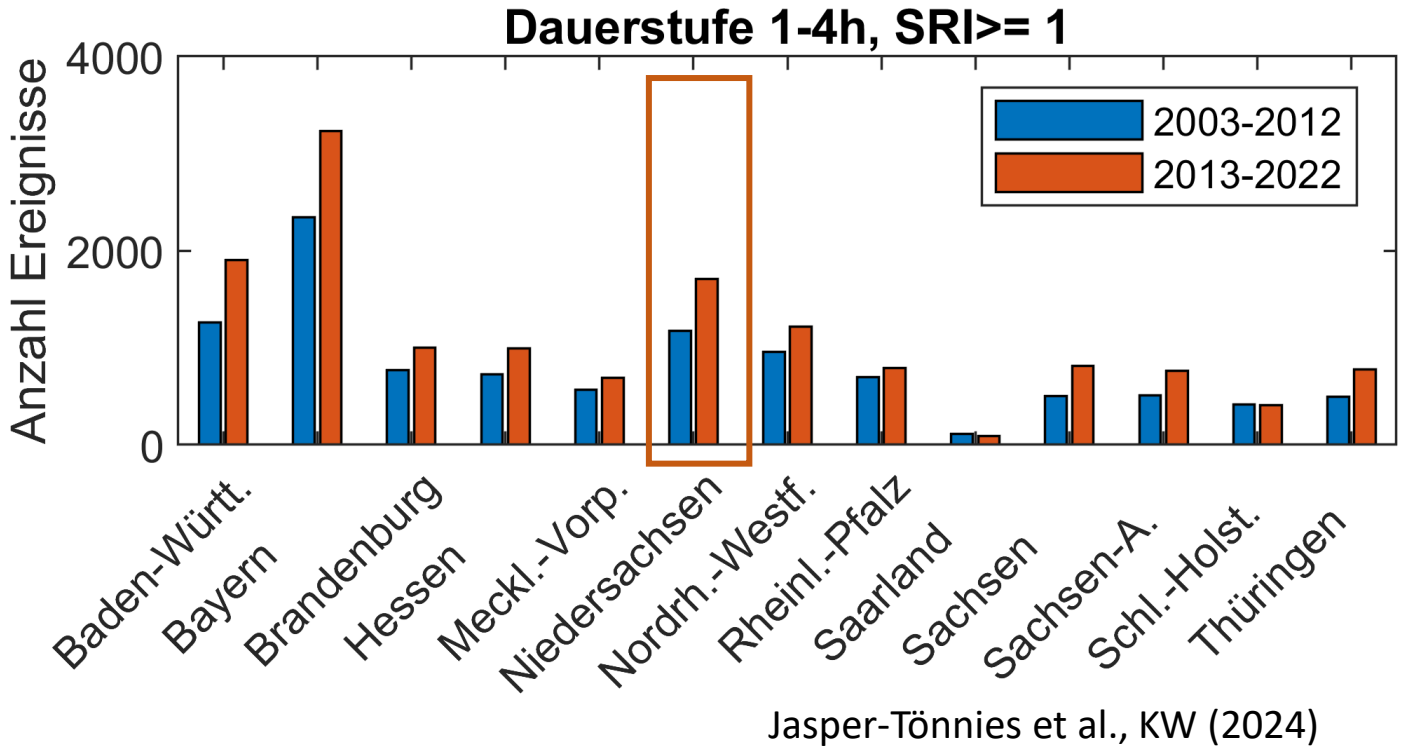
Heavy Rain events from 2013-2022 in Niedersachsen, duration 1-4 h. Source: LAWA-Starkregenportal, starkregenportal.de

Observed trends of extreme precipitation

How robust is this signal compared to other parts of Germany?

Niedersachsen: Relative change: **+ 38 %**

- We find **similar increases** in other parts of Germany:



Jasper-Tönnies et al., KW (2024)

List of uncertainties:

- *Measurement uncertainties*
- *Relative short observation period – impact of special weather situations*
- *Decadal variability*

Future trends of extreme precipitation

What is the future trend of extreme sub-daily precipitation on a sub-catchment scale?

Standard approach: Ensemble of nested simulations GCM – RCM (- CPM) using different future scenarios (e.g. EURO-CORDEX/ ReKliES, RCP2.6, RCP8.5)

Convection permitting models (CPM)

- provide output at the scale of interest (~3km, 1h)
- are computationally very expensive and the number is limited

→ Limited representation of scenario, model and parameterisation uncertainties.

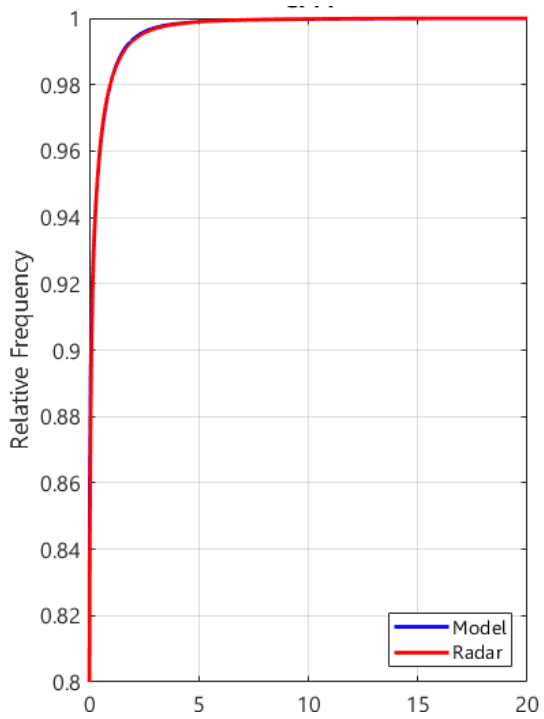
Evaluation of a CPM ensemble:
Ban et al., *Climate Dynamics* 57(2021)

List of uncertainties:

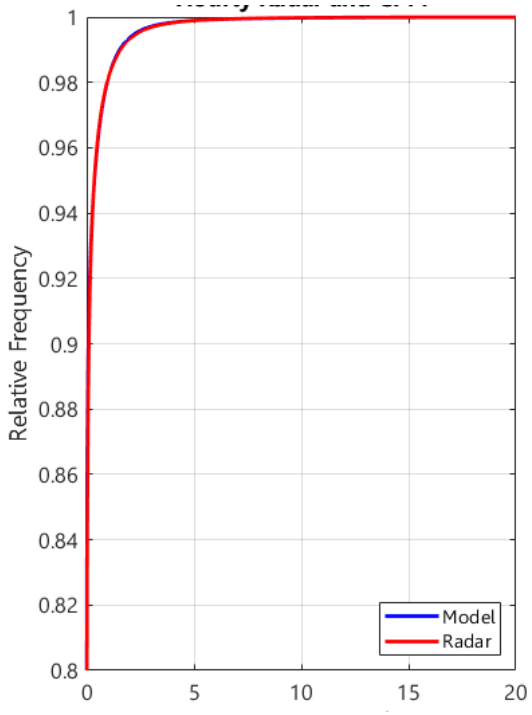
- *Scenario uncertainties*
- *GCM uncertainties*
- *Decadal variability*
- *RCM uncertainties*
- *parametrisations of the sub-grid processes*
- *Model biases*

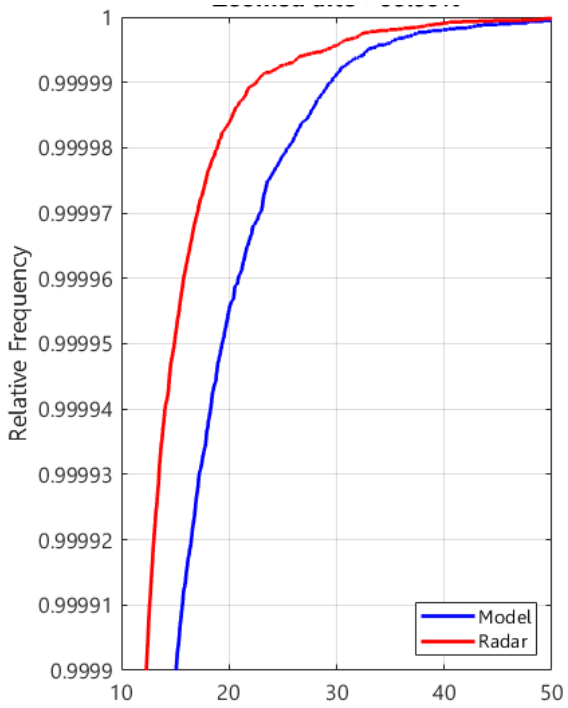
Comparison CPM – observation (Radar)

CDF of Daily precip CPM and radar



CDF of Hourly precip CPM and radar





Precipitation [mm]
Zoomed into > 99,99%

CDFs of Daily and Hourly precipitation sums in the CPM and Radar observations in the period 2001-2018

Physical Mechanisms – CC-Scaling

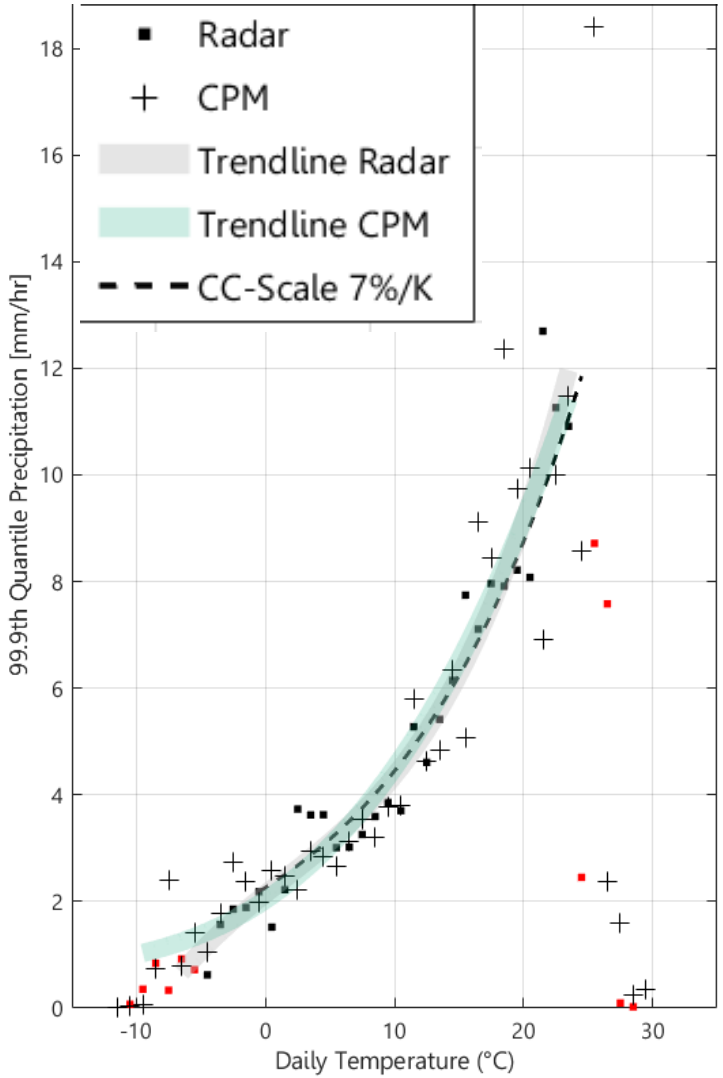
Clausius-Clapeyron equation about the water holding capacity of air in dependence of temperature:

Increasing at: **+7%/K**

- Relation can be found in observations:

Precipitation: Radar
Temperature: DWD weather station
2001-2018, Hanover

99.9% quantile of hourly precip against Daily Mean Temperature



- Relation can be found in simulations
- Here: convection permitting model (CPM)
- Period: 2001-2018, Hanover

Study set-up / validation approach

➢ Use the CPM for validation of a statistical downscaling method

Study set-up:

Choose one GCM as the global climate path: **MIROC5** (Watanabe et al., 2011)

COSMO-CLM-MIROC5 (Rockel et al., 2008)
EURO-CORDEX/REKLIES (EUR-11)
Resolution: 12,5 km, 1 day
(„RCM“)

➔Statistical downscaling

Simple approach (best-prog method + resampling) using **20 years of radar data** with daily precipitation and temperature as predictors
Predictand:
Precipitation with **resolution 2-3 km, 1 hour**

MIROC5-CCLM-CPS (Rybka et al., 2022)
Resolution: 3 km, 1 hour
(„CPM“)

Compare results

Validation of the statistical downscaling: trend

What is the simulated future trend of sub-daily extreme precipitation in Hanover?
Change of extreme Quantiles of hourly precipitation for 2071-2100 (RCP8.5) relative to 2001-2018:

CPM

(MIROC5-CPM, Rybka et al., 2020, DWD)

Q99.9 hourly precip: +28%

Q99.97 hourly precip: +36%

- *Hourly extreme quantiles not well represented*
- *Sub-grid parameterisations may affect trend*

?

Statistical downscaling

(based on daily data from COSMO-CLM-MIROC5, ReKliES, EUR-11)

Q99.9 hourly precip: +12%

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- *Assumptions based on past observations*
- *New extremes not available*
- *Variance is not fully explained by the predictors*

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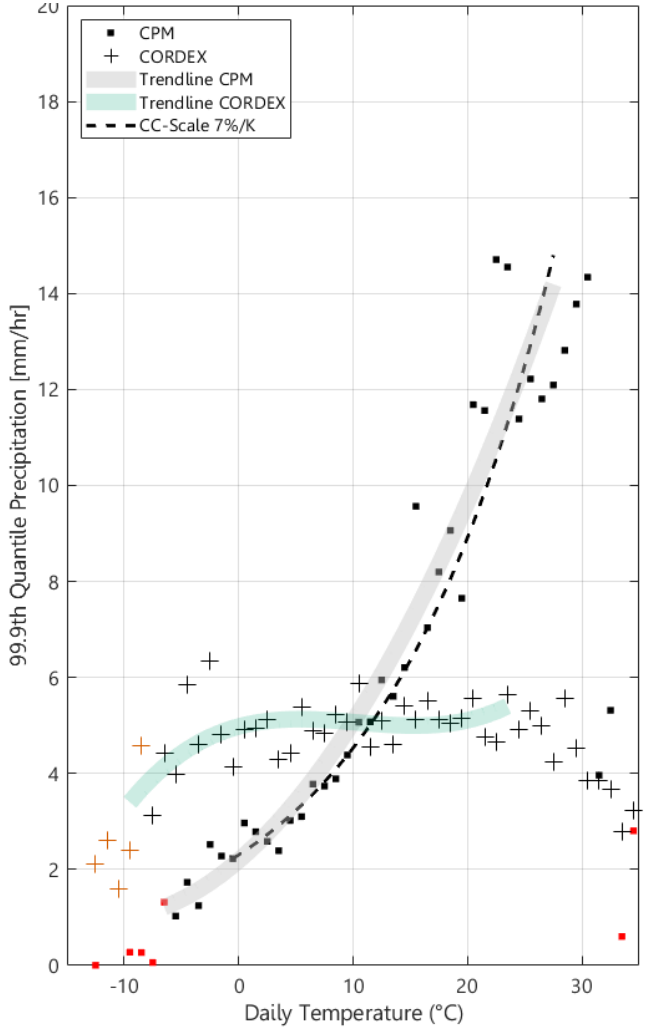
Validation of the statistical downscaling: CC-relation

99.9% quantile of hourly precip against Daily Mean Temperature



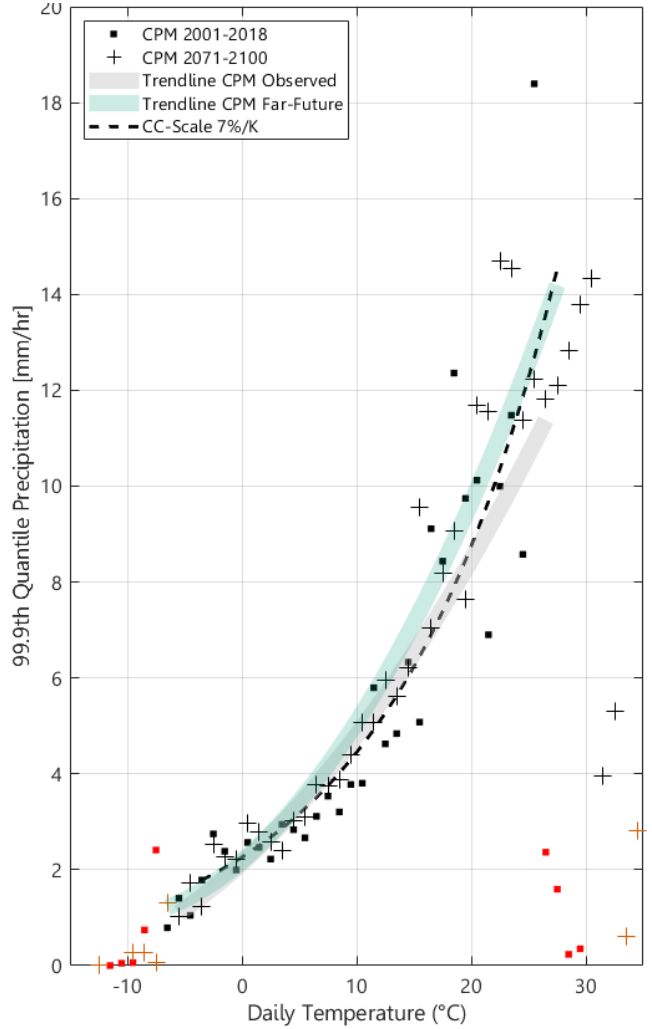
The simple statistical downscaling approach did not reproduce the observed CC-relation.

- This statistical approach is not appropriate to estimate the future trend!

CC-scaling Plot for the period: 2071-2100 (RCP8.5) (green) from RCM derived and statistically downscaled data in comparison to the CPM (grey).

Testing assumptions of the statistical downscaling

99.9% quantile of hourly precip against Daily Mean Temperature



Basic assumption of statistical downscaling of climate model output:

The relation between the larger and the finer scale (here: daily temperature vs. 99.9th percentile of hourly precipitation) does not change in a changing climate.

- This assumption does not seem to hold for sub-daily precipitation in the far future!

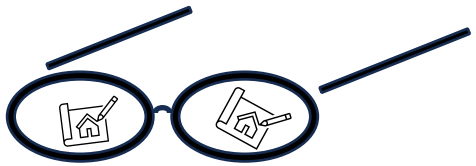
CC-scaling Plot for the period: 2071-2100 (RCP8.5) (green) in comparison to the period 2001-2018 (grey).

Next steps:

Produce input for the Hanover sewer model SIMBA: high resolution time-series for 83 sub-catchments

→ Adapt the statistical downscaling:

- Test other predictor combinations and a larger observation data set for the statistical downscaling in order to better match the observed CC-relation and the CPM trend.



Practical approach:

- Post-process the results produced by the statistical downscaling using the CPM derived trend as a constraint

Conclusions

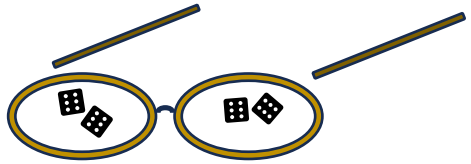
Convection Permitting Models

- reproduce radar observed statistical distributions of daily and (mostly) sub-daily precipitation
- are a major step forward in estimating future sub-daily trends
- With additional radar based statistical downscaling (trends costrained by CPM-derived trends) we can produce high resolution input to the SIMBA model for the Hanover sewer system: time-series for 83 sub-catchments
- Several GCM-CPM runs are available to build a small ensemble

But: Convection Permitting Models remain computationally expensive and the number is limited

→ Limited representation of scenario, model and parameterisation uncertainties.

Outlook



Convection Permitting Model output is available for the far future, providing:

- a dataset with data available both on a high-resolution sub-daily and lower-resolution daily scale
- a dataset with new extremes on a sub-daily scale.

→ This data can be used to:

- derive/ adapt the statistical relations between the scales needed for an improved statistical downscaling of the far future period
- overcome a major shortcoming of the statistical donwscaling

Outlook

- Other pairs of GCM-RCM and GCM-CPM simulations could be used to validate the results.
- If the results are satisfying: statistically downscaling of the complete GCM-RCM ensemble to cover the spread and scenario uncertainties.

…have a set of different lenses in your bag

Thank you for your attention!

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References:

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