High resolution regional climate modeling for flood hazard impact study in Germany

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INTRODUCTION

- An increased variability in precipitation and temperature for the warming future climate is expected.
- The development of adaptation strategies very often requires impact studies on a regional scale, e.g. for flood hazard studies in small and medium sized river catchments.
- Therefore, **ensembles of coupled climate-runoff simulations** are performed for the assessment of changes in flood hazard for small and medium sized river catchments in Germany. This project is funded by CEDIM (Center for Disaster Management and Risk Reduction Technology).
- Our ensemble includes 2 GCMs (ECHAM5, CCCma3) and for one GCM (ECHAM5) three realizations with different initial conditions, **2 RMCs (CCLM, WRF) with a final spatial resolution of 7km and 1 hour output timestep**, and at least two hydrological models for each catchment (see Figure1).

➢ The regional scale of the analysis allows for addressing the following questions:
- How will the flood characteristics for small and medium catchments alter in a changing climate within the next decades?
- What uncertainties are to be expected?

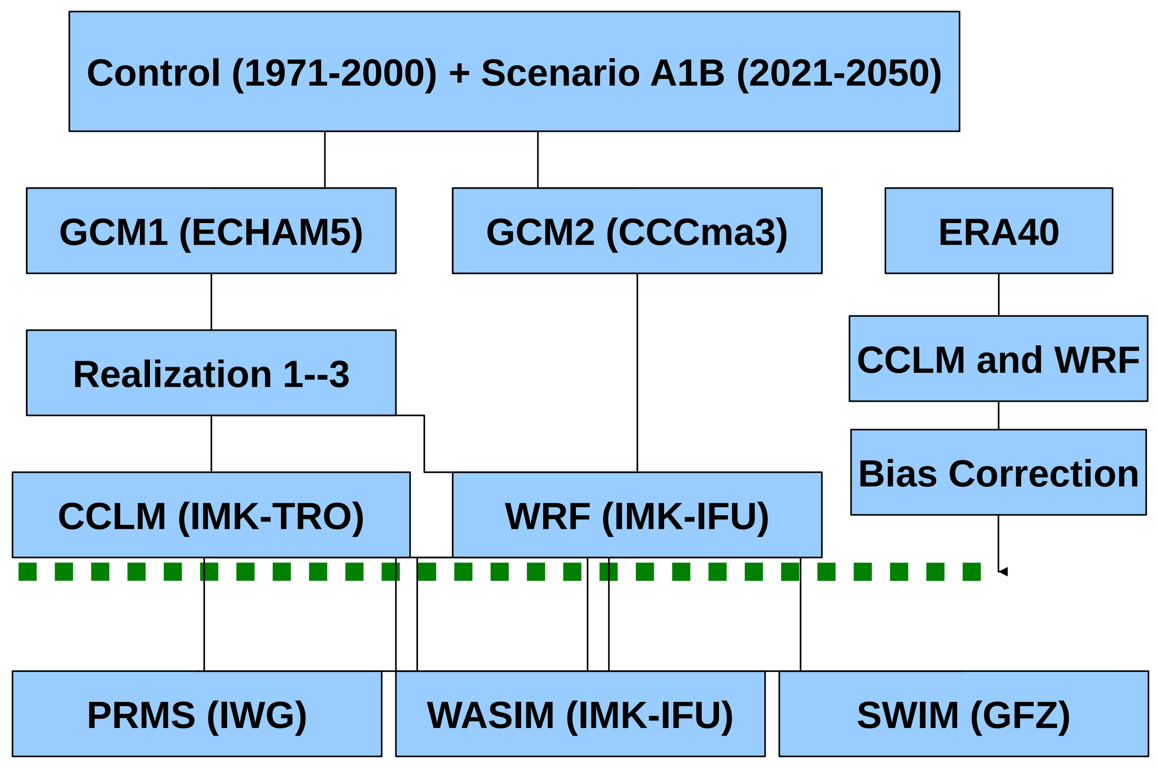
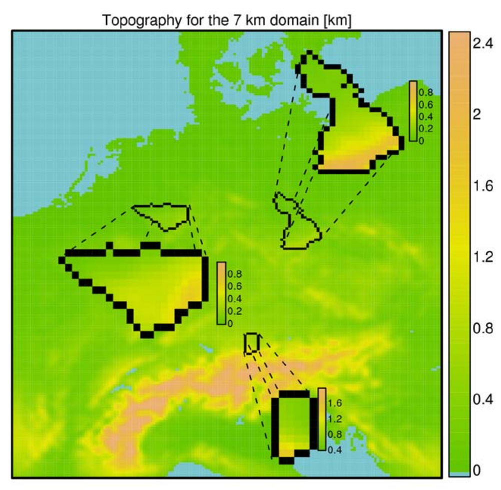


Figure 1: Schematic over the ensemble simulations strategy. The additional step of bias correction is included on the right side of the diagram

Figure 2: RCM Domain 2 (7km) and river catchments under study: Ammer (south), Mulde (east) and Ruhr (west)



PART1: Regional Climate Modeling

SETUP

Double nesting strategy of both RCMs to downscale GCM results:
- Domain1: ~ 50km covering Europe
- Domain2: 7km covering Germany and surroundings
- 41 vertical levels

RESULTS

VALIDATION (1971-2000)

CLIMATE CHANGE SIGNAL (2021-2050 versus 1971-2000)

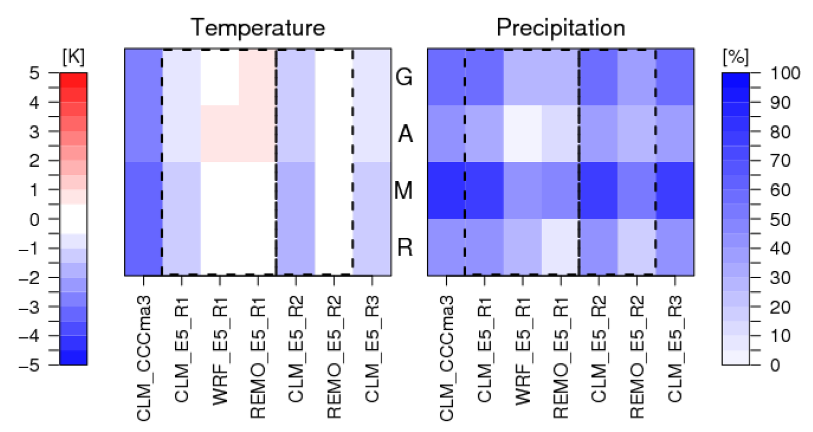
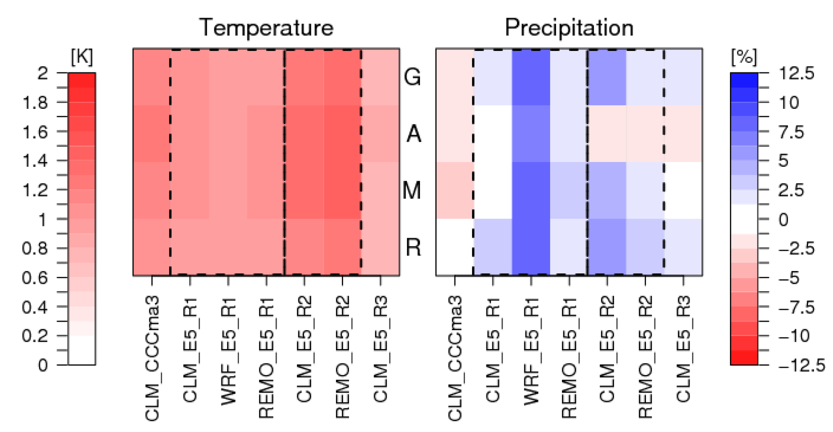


Figure 3
left: Annual mean bias for the CCLM, WRF and REMO control simulations (E520C) for realizations R1-3, plus an CCCma3 driven simulation with CCLM. Spatial averages are shown for Germany ("G"), Ammer ("A"), Mulde ("M"), and Ruhr ("R"). Temperatures are compared to the E-OBS data set [Haylock et al., 2008], and precipitation to the REGNIE data set (DWD)
right: Climate change signal of the RCM simulations described above



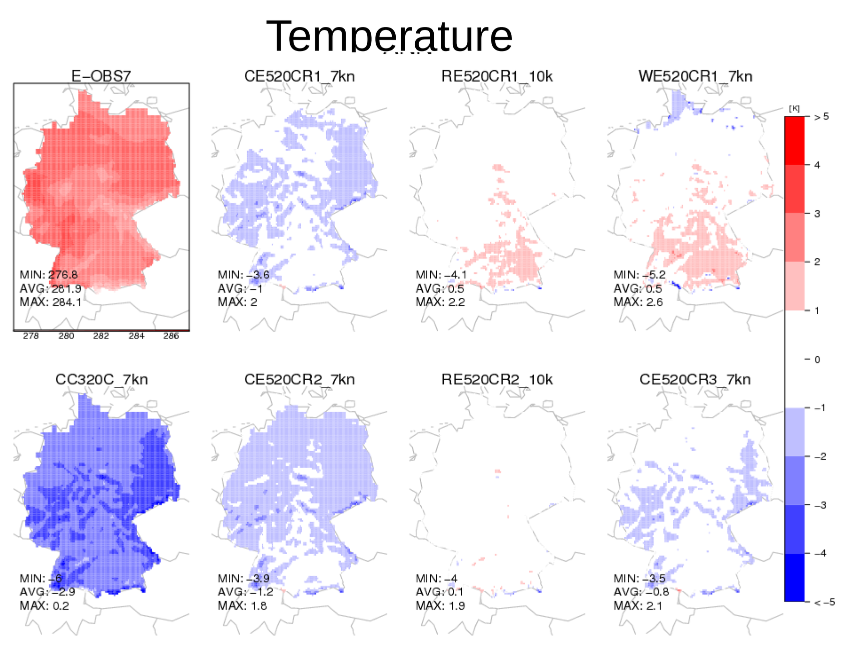
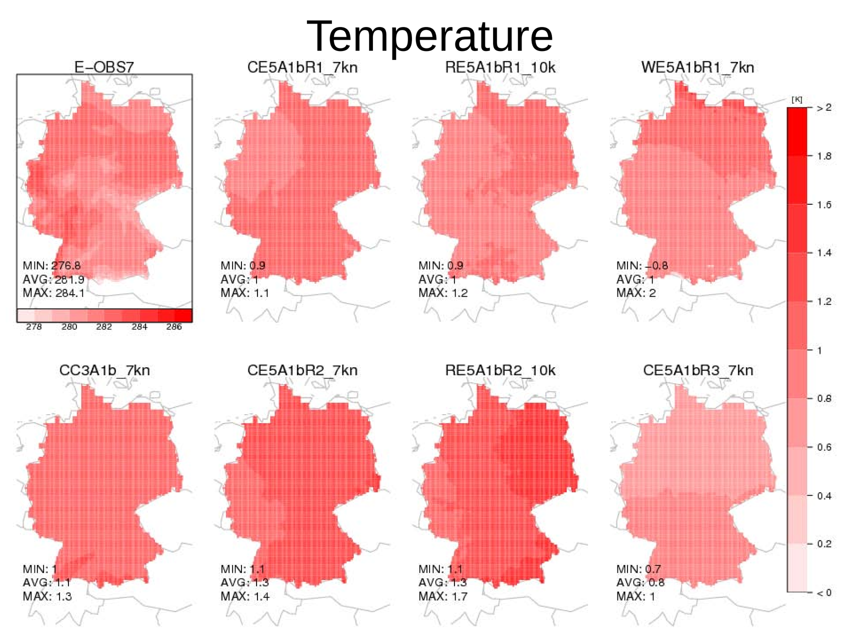


Figure 4
left: Spatial distribution of annual mean temperature bias for the CCLM, REMO and WRF control simulations (E520C) for realization 1 (top line) and CCCma3, CCLM R2, REMO R2, and CCLM R3 (bottom line)
right: Climate change signal of the RCM simulations described above



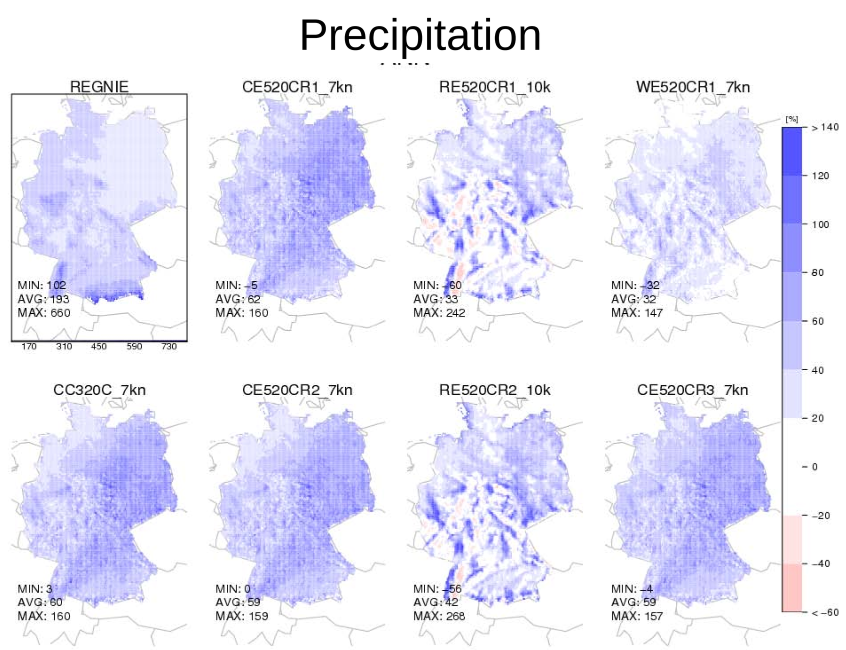


Figure 5
left: Spatial distribution of relative annual mean precipitation bias for the CCLM, REMO and WRF control simulations (E520C) for realization 1 (top line) and CCCma3, CCLM R2, REMO R2, and CCLM R3 (bottom line)
right: Climate change signal of the RCM simulations described above

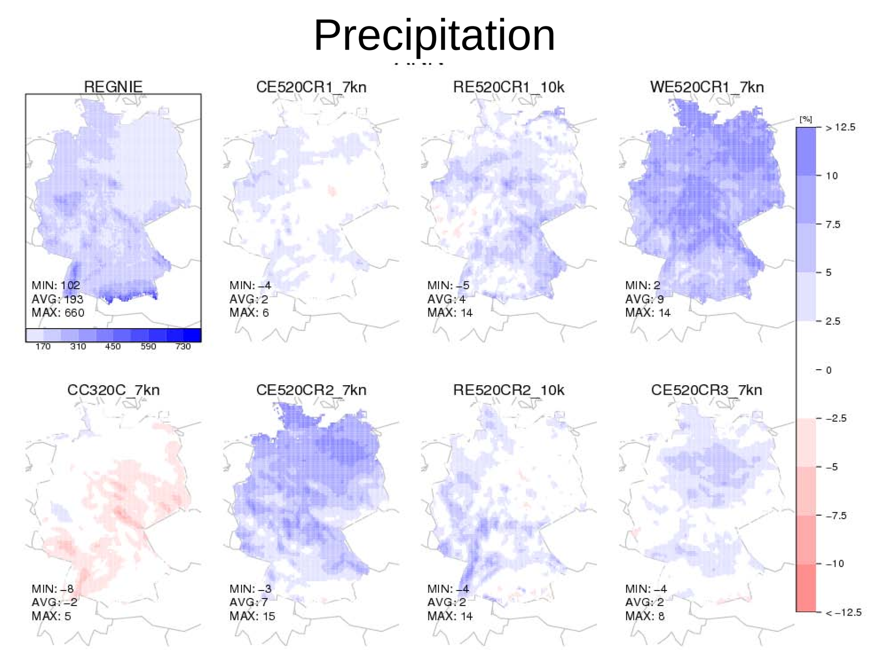
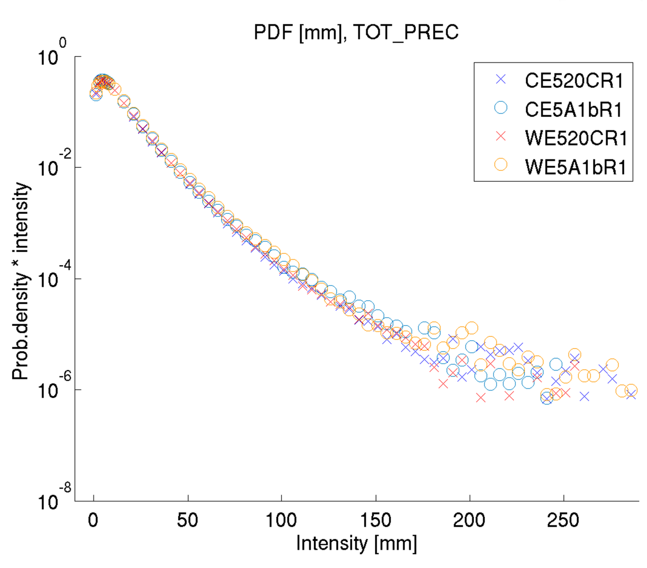
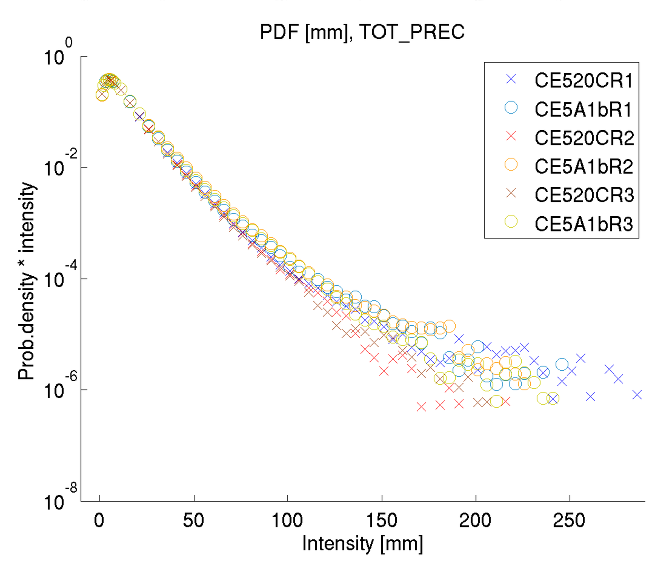


Figure 6: Normalized precipitation intensity distributions [mm] of CCLM and WRF E520C and E5A1B1 for realization 1 (left) and CCLM E520C and E5A1B1 realization 1-3 (right)





Validation of RCM results:

- CCLM model is colder than observations by about 0.5 to 2 K
- WRF and REMO have a warm bias of around 0.5 K
- Precipitation is overestimated by all models (partially also due to GCM input)
- Wet bias is larger in winter for CCLM and WRF (not shown)

Climate Change Signals:

- Temperature increase between 0.8 and 1.3 K
- Change of annual precipitation sum between -2% and 9%; varying spatial distributions for different RCMs and realizations
- Intensity range of realizations 1 to 3 is wider for control simulations compared to the scenario ones
- Increase of high precipitation intensities for WRF and CCLM realization 2 and 3

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Bias correction of RCM results:

- Biases in the RCMs needs to be corrected before coupled to the hydrological modeling
- Bias correction method: **quantile mapping** (not shown)
- Method implementation and application in this project see Berg et al., 2010

References:
Berg, P., D. Düthmann, H. Feldmann, J. Liebert, and S. Wagner (2010), Assessing uncertainties in observations and RCM bias correction, submitted to International Journal of Climatology.

Haylock, M., N. Hofstra, A.M.G. Klein Tank, E.J. Klok, P.D. Jones, and M. New (2008), A European daily high-resolution gridded dataset of surface temperature, precipitation and sea-level pressure, J. Geophys. Res., 113, D20119,doi:10.1029/2008JD010201.

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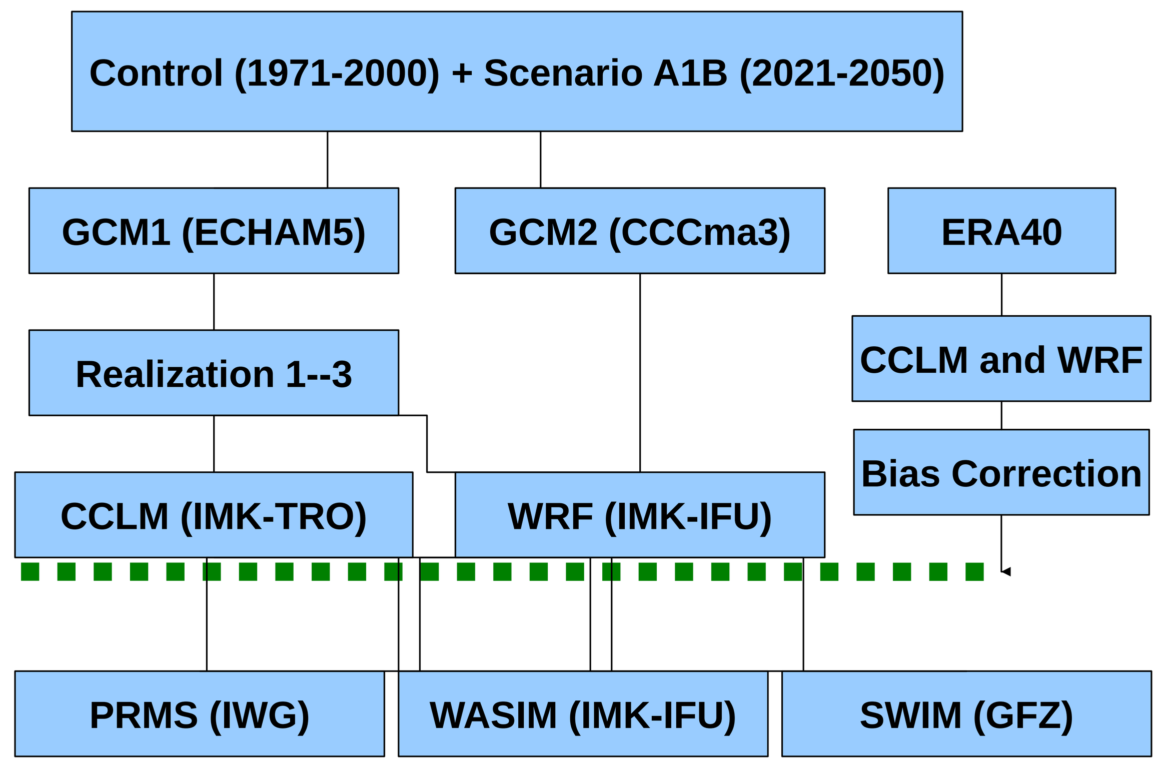


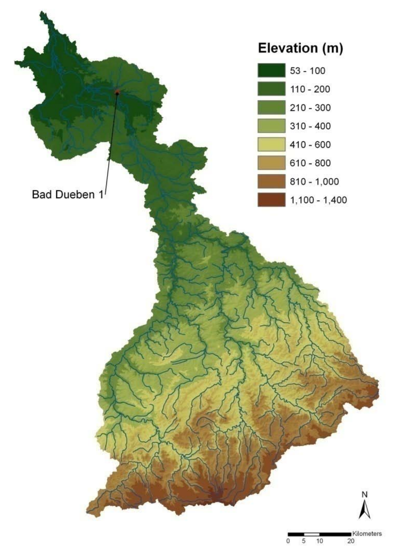
Figure 1: Schematic over the ensemble simulations strategy. The additional step of bias correction is included on the right side of the diagram.

PART2: Flood hazard impact study

SETUP

- Hydrological simulations are performed for three representative small to medium sized catchments in Germany (Ammer, Mulde, Ruhr) with catchment areas between 700 and 6000 km² applying at least two different hydrological models per catchment
- All model setups are calibrated and validated using meteorological observations before applying RCM results (not shown)

Figure 7: Digital elevation model of the Mulde catchment and location of the gauge Bad Dueben



RESULTS

mean monthly discharge [m³/s] (30 year average)

maximum monthly discharge [m³/s] (30 year average)

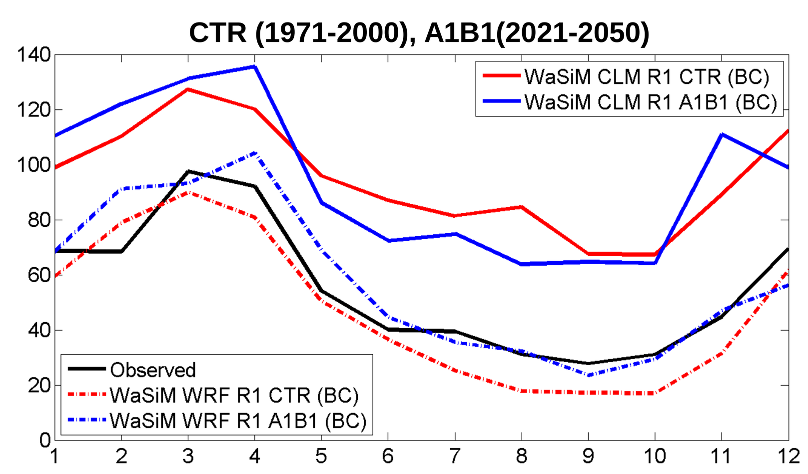
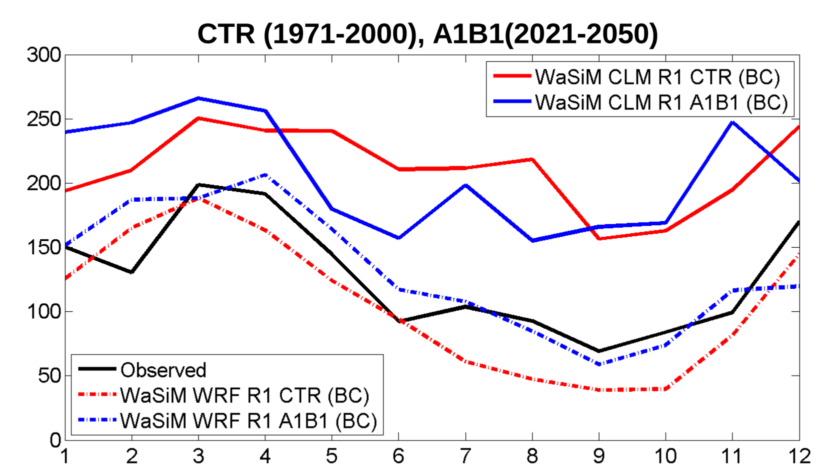


Figure 8
left: Mean monthly discharge at Bad Dueben of the WaSiM simulations with the bias corrected 7km ECHAM5 realization R1 data using the RCMs CCLM and WRF for the control (CTR, 1971-2000) and scenario (A1B1, 2021-2050) period
right: Maximum monthly discharge of the simulation results described above



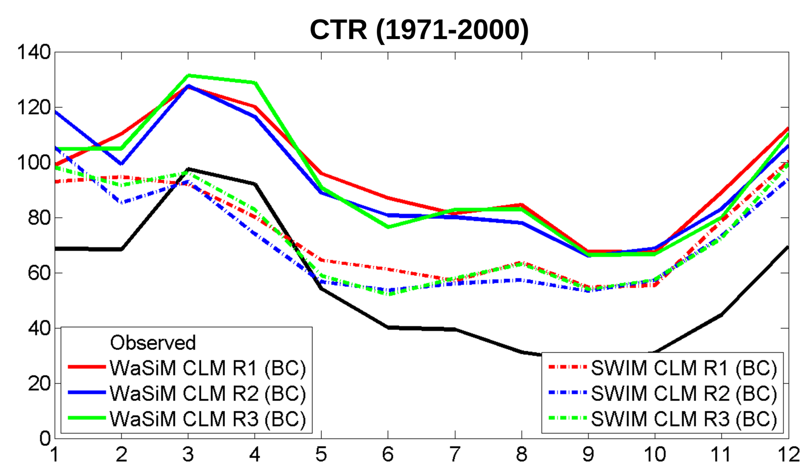
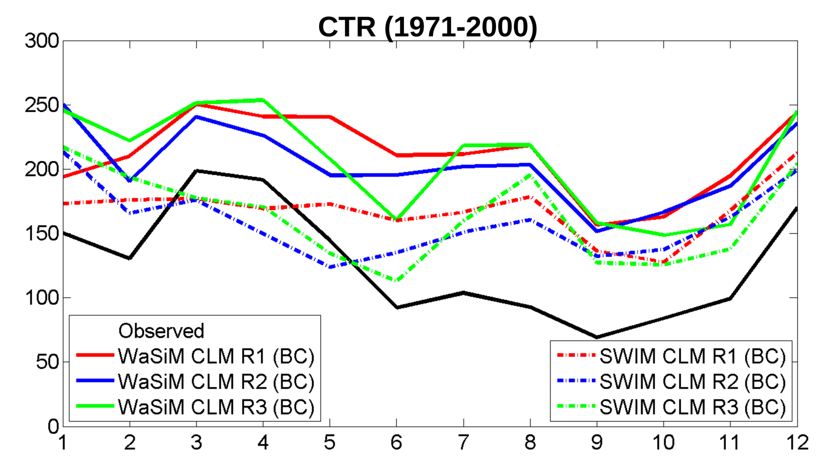


Figure 9:
left: Mean monthly discharge at Bad Dueben of the WaSiM and SWIM simulations with the bias corrected 7km ECHAM5 realization R1, R2, and R3 using the RCM CCLM for the control (CTR, 1971-2000) period
right: Maximum monthly discharge of the simulation results described above



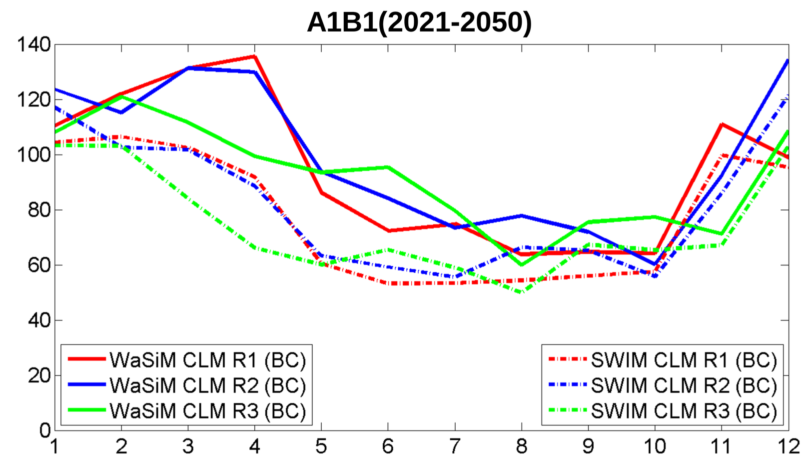
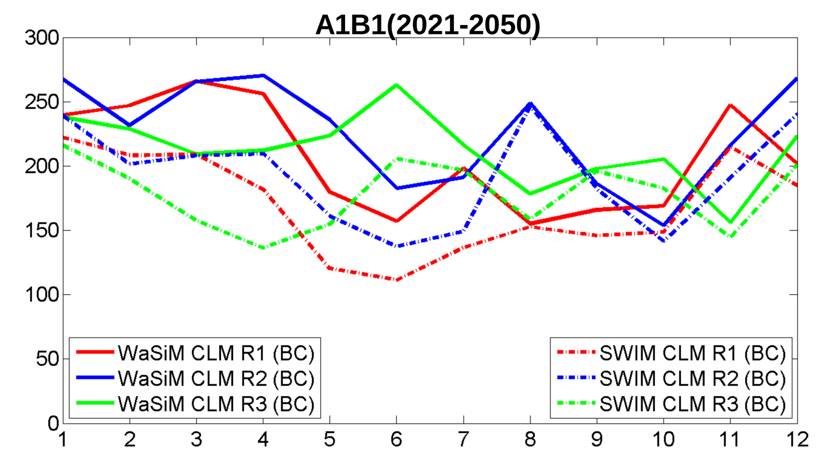


Figure 10
left: Mean monthly discharge at Bad Dueben of the WaSiM and SWIM simulations with the bias corrected 7km ECHAM5 realization R1, R2, and R3 using the RCM CCLM for the scenario (A1B1, 2021-2050) period
right: Maximum monthly discharge of the simulation results described above



Discussion:

- The selection of the RCM significantly impacts the hydrological modeling result for both mean and maximum discharge in spite of bias correction
- Both RCMs estimate higher mean and maximum discharge in winter and spring. In summer the signal is different

- The selection of the hydrological model also impacts the hydrological modeling result significantly
- Seasonal cycle of mean and maximum discharge of both hydrological models is comparable, but there is an offset if using WaSiM
- The offset decreases partially for the scenario period

- The impact of the selection of realization R1,R2, or R3 of the GCM is minor for the mean values compared to the aforementioned differences. But for the scenario period the differences increase
- For the maximum discharge values the impact is in the same order of magnitude compared to the selection of the RCM and the hydrological model

CONCLUSIONS

➢ Regional climate modeling analysis has shown that the selection of the GCM, the realization of the GCM, and the selection of the RCM significantly impacts the simulation result. All ensemble simulations estimate a temperature increase of around 1°C and an increase in annual precipitation (except the CCCma3) for the scenario period 2021-2050 for Germany.

➢ The validation of the RCM results has shown the need for bias correction using the quantile mapping method before coupling to the hydrological model.

➢ The flood impact study performed so far indicates that the selection of the RCM, the selection of the GCM and its realization impacts the hydrological modeling results significantly. Furthermore, the selection of the hydrological model causes different modeling results.

➢ Climate impact analysis considers so far only simulation results of two hydrological models for one catchment. It is expected that the ensemble simulations in particular for the other two catchments support a more detailed assessment of climate change signals in context of the large uncertainties involved within the modeling chain.

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