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Brief Communication: An update of the article "Modeling flood damages under climate change conditions – a case study for Germany"

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Abstract

In our first study on possible flood damages under climate change in Germany, we reported that a considerable increase in flood related losses can be expected in future, warmer, climate. However, the general significance of the study was limited by the fact that outcome of only one Global Climate Model (GCM) was used as large scale climate driver, while many studies report that GCM models are often the largest source of uncertainty in impact modeling. Here we show that a much broader set of global and regional climate model combinations as climate driver shows trends which are in line with the original results and even give a stronger increase of damages.

1 Introduction

Many studies have pointed out that an increase in temperature will amplify the hydrological cycle and intense precipitation will increase (Kundzewicz and Schellnhuber, 2004). This is confirmed in a recent study by Lehmann et al. (2015) showing that there is indeed a trend to more intense precipitation worldwide which is in line, in general, with the Clausius–Clapeyron equation (relation of temperature to saturation vapor pressure, Pall et al., 2007). An increase in specific air humidity and intense precipitation as well as in frequency of "wet" atmospheric circulation patterns has also been reported for Germany (Hattermann et al., 2012).

This is why the German Insurance Association has commissioned a study with the aim to estimate what flood damage would occur in individual river reaches of Germany under warmer climate (published in Hattermann et al., 2014). In this specific study, the insurers were interested solely in the pure "climate change" impact on flood hazard and related flood damages, thereby keeping other drivers constant (change in infrastructure, value of assets, improved protection etc.). One main objective of the study was to analyze and quantify the sensitivity of results to climate scenario and model uncertainty.

A drawback of the study was that at the time when the project started, only a limited number of regional climate projections was available for the impact study, and these projections were only driven by one Global Circulation Model (GCM), so that the general significance of the outcome was limited, because different recent studies show that GCM models are often the largest source of uncertainty in impact modeling (cf. Vetter et al., 2015).

Meanwhile, new sets of regional climate scenarios driven by different combinations of GCMs and Regional Climate Models (RCMs) are available, and the principal research question addressed in this short communication is to crosscheck the robustness of the overall outcome of the first study, viz. that an increase in temperature will likely lead to an increase in flood hazard and flood related losses, by applying a larger ensemble of climate change scenarios and scenario runs as driver for the impact study.

The methodology to come from global climate change to impacts on flood hazard and damages in Germany used here is exactly the one described in Hattermann et al. (2014). In short, considered in the analysis are 5473 river sections of the five largest river basins in Germany (the Rhine, the Danube, the Elbe, the Weser and the Ems), thereof 3766 ones in Germany. The changes in climate are transformed into changes in flood hazards on a daily time step using the eco-hydrological model SWIM (Krysanova et al., 2002), and the related damages are calculated using river section specific damage functions as provided by the German Insurance Association (GDV, Gesamtverband der Deutschen Versicherungswirtschaft) using their flood loss model HQ Kumul (see Hattermann et al., 2014). Taken into account in the damage functions are human estates and small enterprises.

The SWIM model has previously been implemented for the main German rivers by Hattermann et al. (2005) and Huang et al. (2010) and applied in various impact and adaptation studies (Hattermann et al., 2004; Huang et al., 2009, 2010). Investigation of climate change impacts on floods using the results of different RCMs as climate boundary condition was carried out by Huang et al. (2013) and Hattermann et al. (2011).

2 The climate forcing data

While in the original study 7 climate projections of 2 RCMs (REMO, Tomassini and Jacob, 2009 and CCLM, Böhm et al., 2006) driven by only one GCM (ECHAM5, Röckner et al., 2003) were used, two newer climate data sets with a much broader combination of driving GCMs and RCMs are available now and applied in this follow up analysis to estimate the robustness of the outcome of the original study: the first one stems from the ENSEMBLES project (Van der Linden and Mitchell, 2009), of which 13 GCM/RCM combinations all for the SRES A1B emission scenario were taken as climate drivers for the impact estimation. The spatial resolution of these RCM data is approximately 25km. For the HadCM3 GCM as well as the HadRM3 RCM, three realizations were included for "normal" climate sensitivity (Q0), "low" climate sensitivity (Q3) and "high" climate sensitivity (Q16) to the external forcing (e.g. greenhouse gas concentrations, by perturbing HadRM3 internal parameters, see Collins et al., 2006). The most recent set of climate scenario data are projections delivered by the CORDEX initiative (Coordinated Downscaling Experiments, Jacob et al., 2014), an internationally coordinated framework to produce improved regional climate change projections with a focus on climate change impact and adaptation studies. Also in CORDEX, a combination of GCMs and RCMs was applied of which we selected 11 uncorrected and 4 bias corrected runs for the RCP (Representative Concentration Pathway) scenario 8.5 (additional radiative forcing 8.5 $\mathrm{W\,m^{-2}}$ until end of the century) and 4 bias corrected runs for the RCP scenario 4.5 and with a time horizon until 2100. The bias correction was done using a quantile mapping method (cf. Gobiet et al., 2015; Wilcke et al., 2013). The combinations of GCMs and RCMs used in the study are listed in the Appendix.

In all climate projections, temperature shows a robust and statistically significant warming over Europe, with regional differences, in the range of 1–4.5° for RCP4.5 and of 2.5–5.5° for RCP8.5, the latter encompassing the warming range projected for the A1B scenario, with temperature increases between 3 and 4.5° (Jacob et al., 2014).

3 Results

Figure 1 gives the changes in flood related damages under a warmer future when considering different sets of climate ensemble projections. The results are compared for three future periods (2011–2040, 2041–2070 and 2071–2100) against the reference periods 1961–2000 (Hattermann et al., 2014, and ENSEMBLES) and 1971–2010 (CORDEX, starting only in 1971). From the results it is visible that (a) the general outcome of the original study (an overall increase of flood related damages in a warmer climate) is confirmed by the new results, (b) the flood related damages even increase when using the new climate data sets as drivers, and (c) the simulated uncertainty is rising with increasing number of scenario projections. The increase until the end of the century is the strongest within the "high end scenario" RCP8.5 with more than 300 % and the increase is more than 200 % within the ENSEMBLES scenario (see Table 1).

In Fig. 2, the damages are compared for the 4 bias corrected RCP4.5 and RCP8.5 projections. Visible is that the average increase in damages is almost the same during the first period, in compliance with the very similar temperature increase in both scenarios. The differences increase in the second and third scenario period, with an approximately 36 % higher average in the RCP8.5 projections until 2100. In total, all projections show generally an increase in damages, but uncertainty is high and single runs may have a slight decrease in damages from one scenario period to another.

4 Conclusions

While the general significance of the original study was limited by the low number of GCM/RCM combinations, the new results with a much higher variety of climate projections as input for the damage estimation give a strong indication that flood related damages will increase in Germany in a warmer climate without implementation of counteracting adaptation measures.

Appendix A: Tables of the climate model data used in the study

Tables A1 to A4 give the different combinations of driving GCMs and nested RCMs.

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Table 1. Average damages per period and scenario projection [million EUR].

Climate projection	Reference	2011–2040	2041–2070	2071–2100
Original	464.7	854.6	886.5	992.7
ENSEMBLES	512.8	1402.1	1288.9	1717.2
CORDEX RCP8.5	494.5	1287.7	1561.2	2145.7

Table A1. Scenario data matrix used in Hattermann et al. (2014).

	Institute	DWD	MPI
	RCM	CCLM	REMO
	Resolution	0.18°	10 km
GCM		MPI-ECHAM5	MPI-ECHAM5
Scenario (# runs)		A1b(2), B1(2)	A1b(1), A2(1), B1(1)
Period		1951–2100	1951–2100

Table A2. Fourteen selected GCM/RCM simulations (SRES A1B) from the ENSEMBLES project (Van der Linden and Mitchell, 2009).

	Institute	C4I	DMI	ETHZ	HC			ICTP	KNMI	MPI	SMHI
	RCM	RCA3	HIRHAM5	CLM3.21	HadRM3 Q0	HadRM3 Q3	HadRM3 Q16	REGCM3	RACMO2	M-REMO	RCA3
GCM	*Resolution*	25 km	25 km	25 km	25 km	25 km	25 km	25 km	25 km	25 km	25 km
HC HadCM3 Q0				1951–2100	1951–2100					1951–2100	
HC HadCM3 Q3						1951–2100					1951–2100
HC HadCM3 Q16		1951–2100					1951–2100				
MPI-MET ECHAM5 r3			1951–2100					1951–2100	1950–2100		1950–2100
CNRM Arpege			1951–2100								
UIB BCM			1961–2099								1961–2100

Table A3. CORDEX-EUR-11 simulation matrix for RCP8.5 used in the study.

RCM8.5	*Institute*	SMHI	MPI – CSC	KNMI		DMI
	RCM	RCA4	REMO2009	RACMO22E	CLMcom-CCLM4-8-17	DMI-HIRHAM5
GCM	*Resolution*	0.11°	0.11°	0.11°	0.11°	0.11°
MOHC-HadGEM2-ES		1971–2100				
ICHEC-EC-EARTH		1971–2100		1971–2100	1971–2100	1971–2100
MPI-M-ESM-LR		1971–2100	1971–2100		1971–2100	
CNRM-CERFACS-CNRM-CM5		1971–2100			1971–2100	
IPSL-CM5A-MR		1971–2100				

Table A4. Bias-corrected CORDEX-EUR-11 simulations for RCP4.5 and RCP8.5 used in the study (Wilcke et al., 2013; Gobiet et al., 2015).

	Institute	SMHI	MPI – CSC	KNMI
	RCM	RCA4	REMO2009	RACMO22E
GCM	*Resolution*	25 km	25 km	25 km
MOHC-HadGEM2-ES		1971–2100		
ICHEC-EC-EARTH		19 71–2100		1971–2100
MPI-M-ESM-LR			1971–2100	

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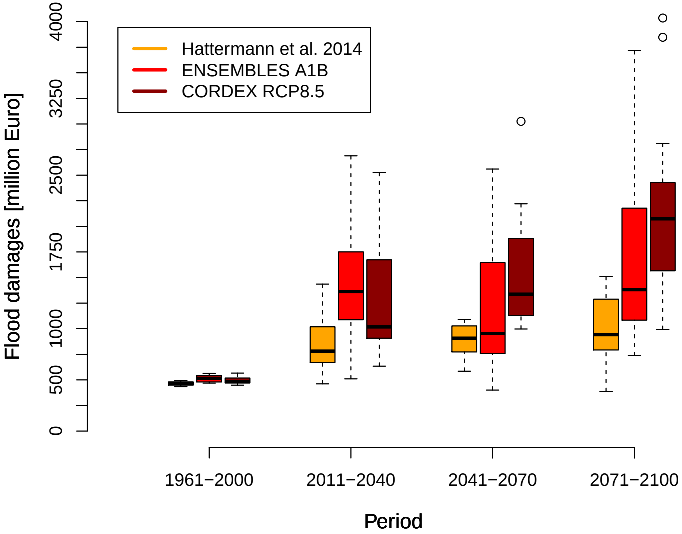

Figure 1. Monetary losses simulated with different ensembles of climate projections as input.

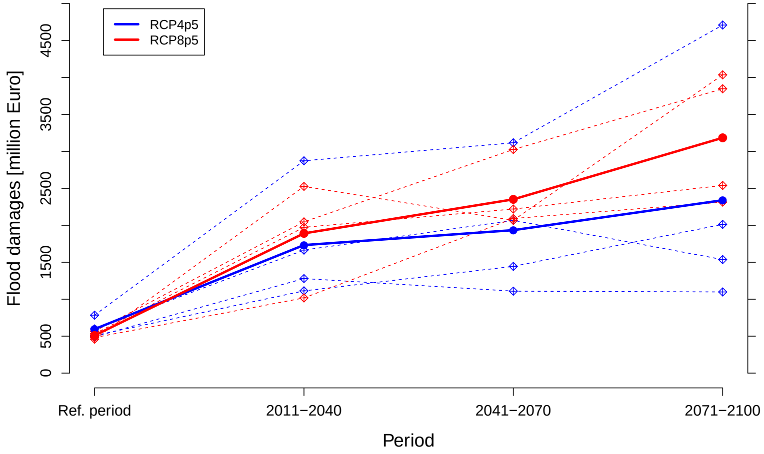

Figure 2. Comparison of impacts on monetary losses when using RCP4.5 or RCP8.5 scenarios as climate driver. The dashed lines show the single runs, the solid lines the averages per period.