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Major floods:
After the game is before the game!

Fred F. Hattermann

Shaochun Huang, Hagen Koch, Valentina Krysanova … and many others

Potsdam Institute for Climate Impact Research

Leibniz Gemeinschaft

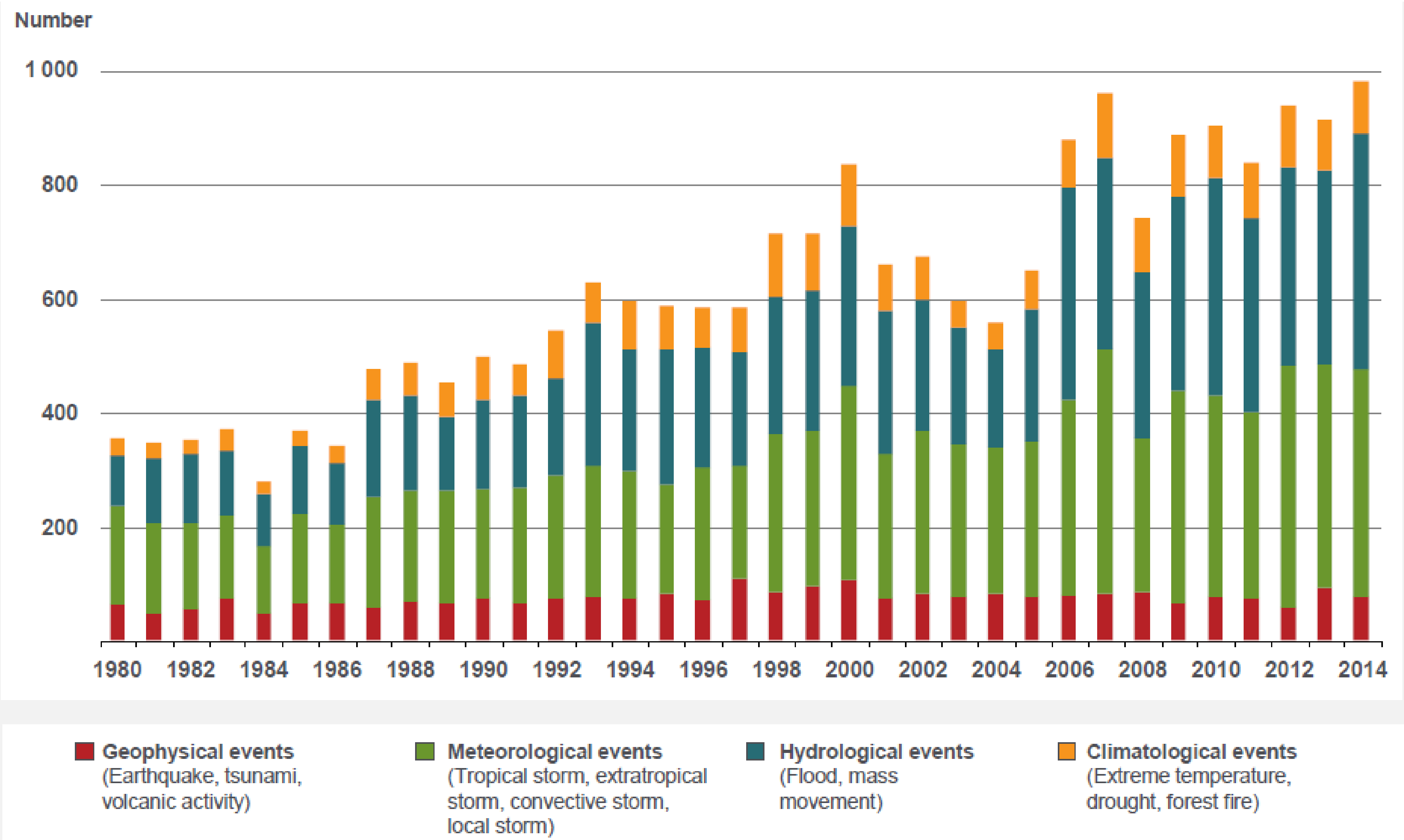
Potsdam Institute for Climate Impact Research
RD2 Climate Impacts & Vulnerability

Outline

- Hydro-meteorological extremes under climate change
- Increasing flood risk in Germany
- Outlook




Number of major events 1980 – 2014 worldwide



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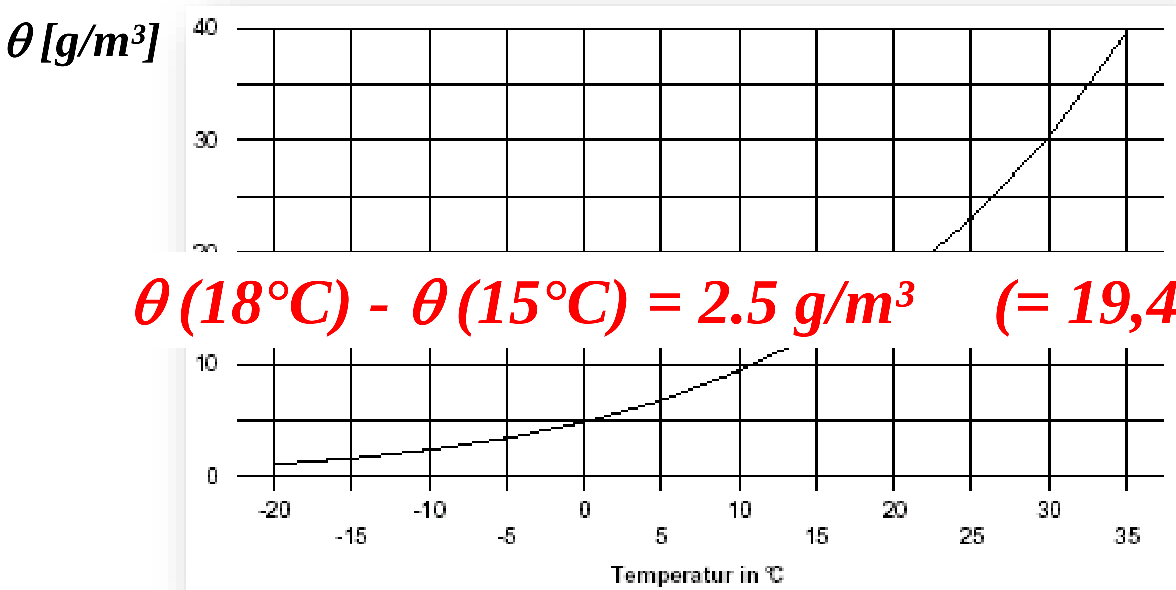
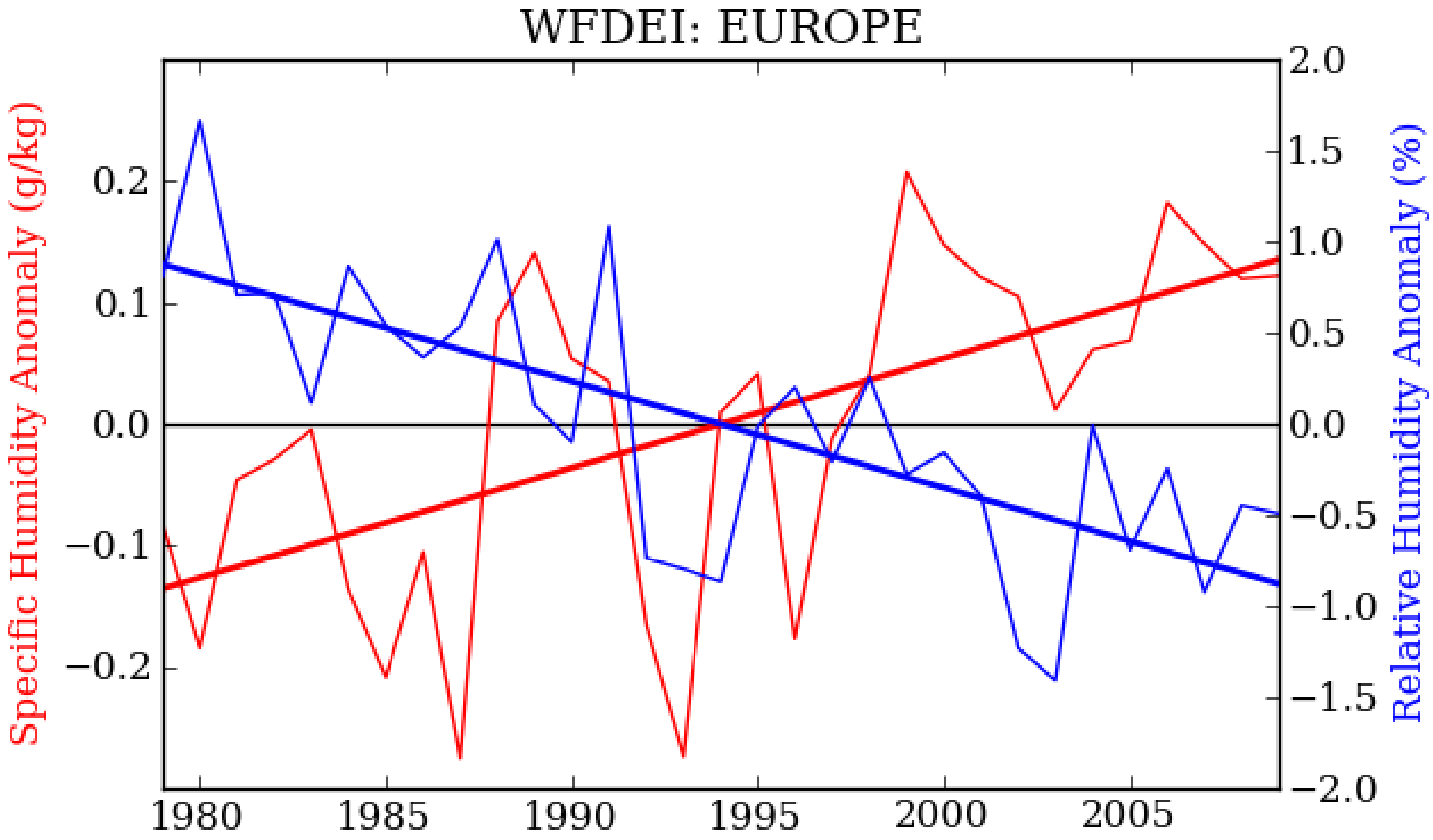
Clausius-Clapeyron: saturated moisture content in the atmosphere is a non-linear function of temperature



$\theta(18°C) - \theta(15°C) = 2.5\ g/m^3$ (= 19,4 %)

Temperature [°C]	0	10	15	18	20
Saturated moisture content [g/m³]	4.8	9.4	12.9	15.4	17.3

Trends in relative and absolute humidity in Europe



Stationarity is dead!

Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P., Stouffer, R.J. (2008) Stationarity is dead: whither water management? *Science*, 319, 573-574.

Co-operation with the leading insurance companies (German Insurance Association)

Leading questions:

- How will climate change impact on flood generation in Germany?
- Do we have more or less intense floods under climate change?
- What is the approximate magnitude of the projected losses?

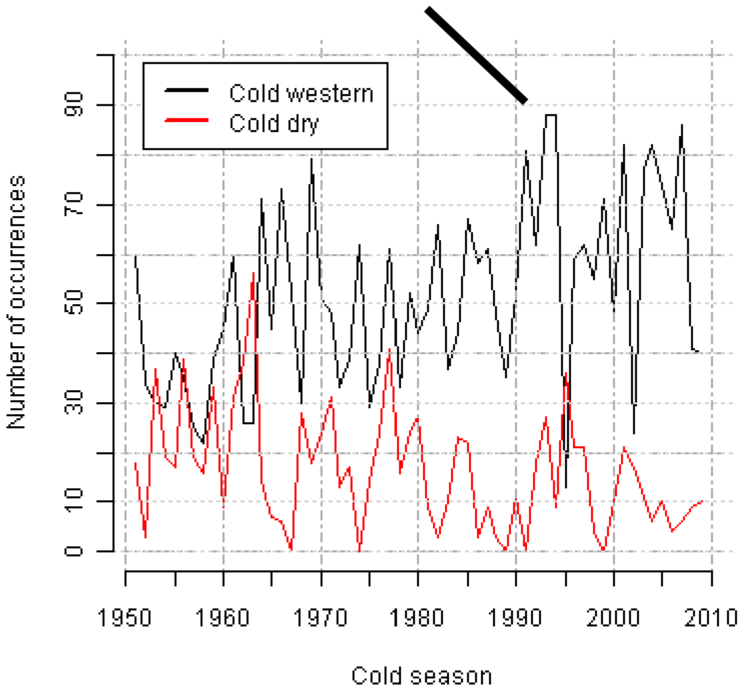
Group meetings with the insurance experts every 2-3 month

Outline

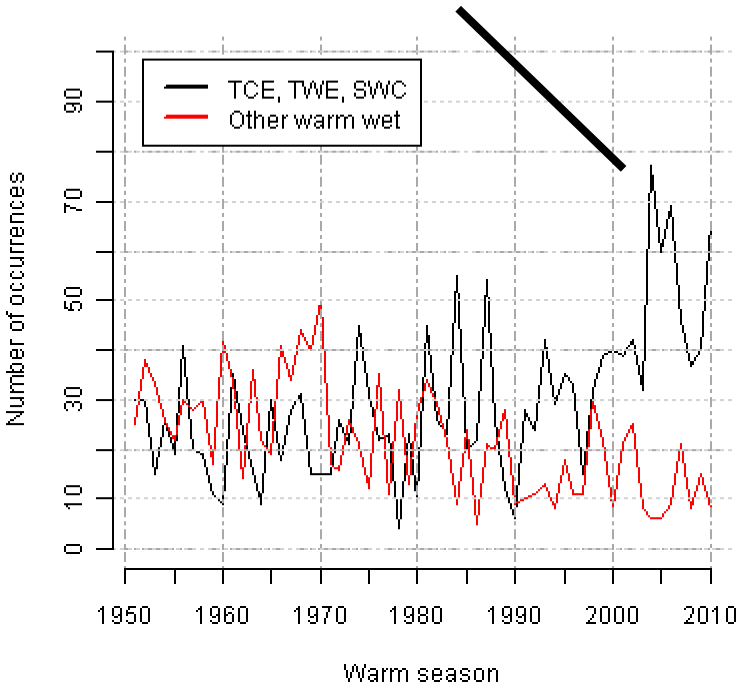
- **Hydro-meteorological extremes under climate change**
- **Increasing flood risk in Germany**
- **Outlook**

Observed trends in circulation pattern

Very humid west wind pattern (origin: Atlandic)



Very humid Vb-weather pattern (origin: Mediterranean)



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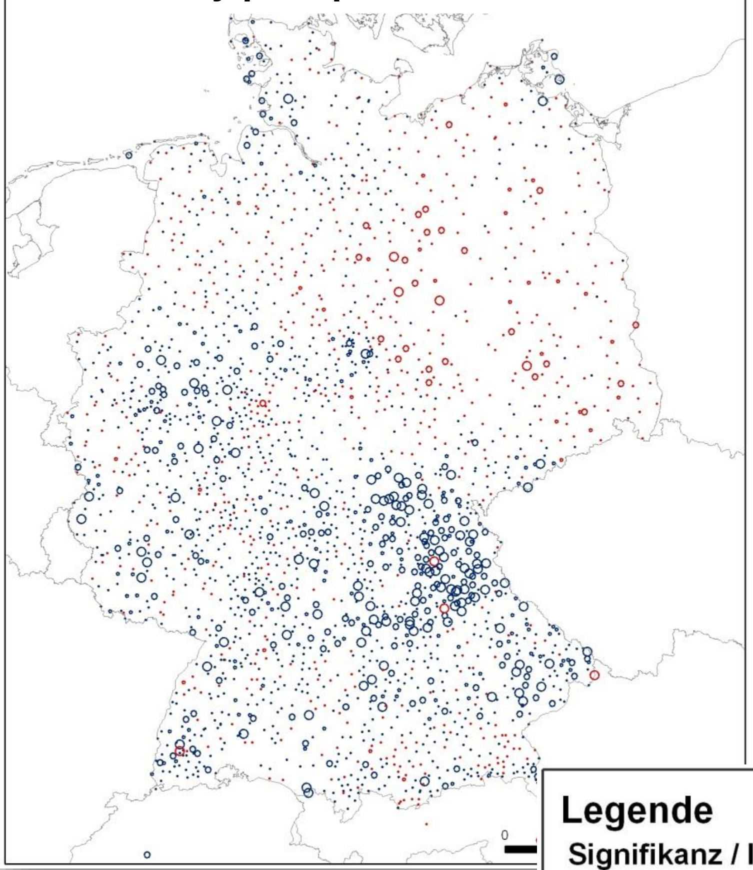
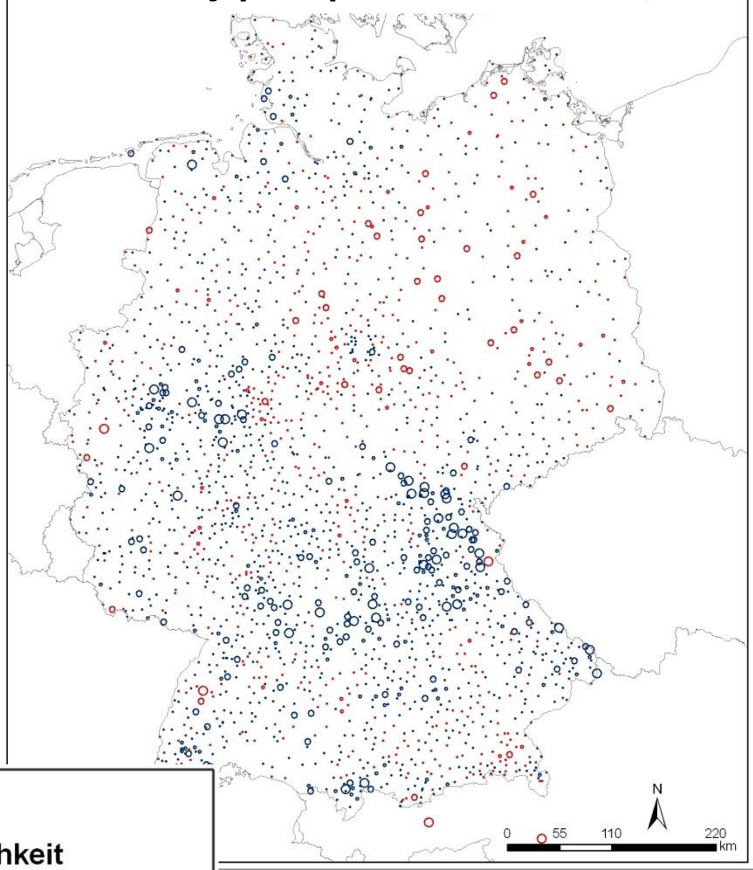
Data: DWD, Modelling: PIK
Hattermann et al. 2012a&b

Introduction Observed trend in intense precipitation (1951-2006)

Daily precipitation > 20 mm



Daily precipitation > 30 mm



Legende

Signifikanz / Irrtumswahrscheinlichkeit

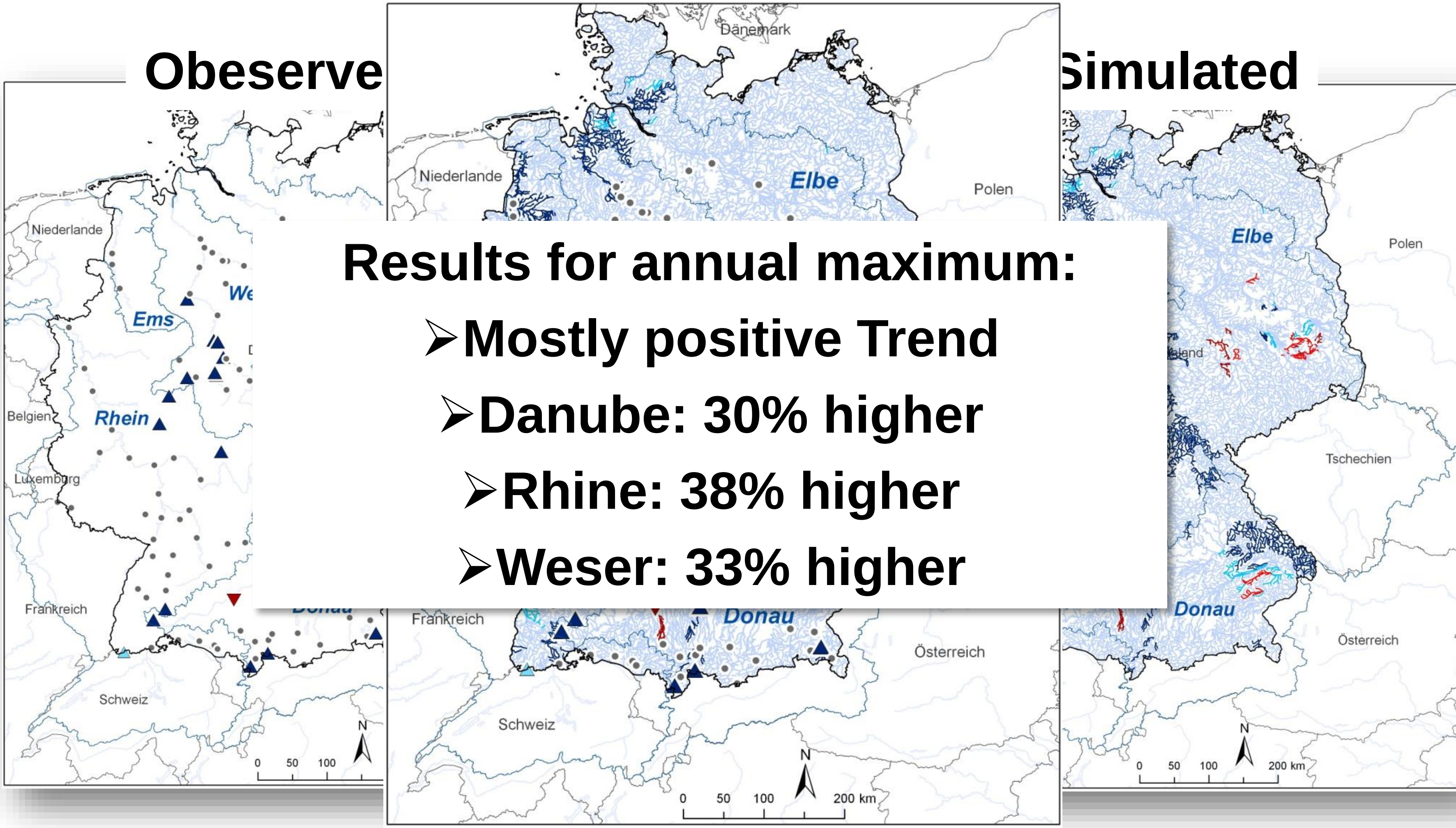
Starkniederschläge Gesamtjahr [> 30 mm/d]

< - 10 %	0 - 1 %
-10 - -5 %	1 - 5 %
-5 - -1 %	5 - 10 %
-1 - 0 %	> 10 %

Data: DWD, Modelling: PIK
Hattermann et al. 2012a&b

Introduction Trend in annual flood maximum 1951-2003

Obeserve | Simulated



Results for annual maximum:

- ➢Mostly positive Trend
- ➢Danube: 30% higher
- ➢Rhine: 38% higher
- ➢Weser: 33% higher

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Data: DWD, Modelling: PIK
Hattermann et al. 2012a&b

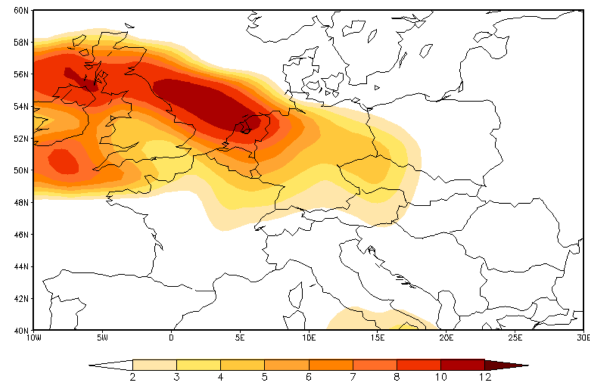
Methodology: From climate extremes to financial losses

Step 1: regional climate by CCLM and REMO (multiple scenario and realisations)

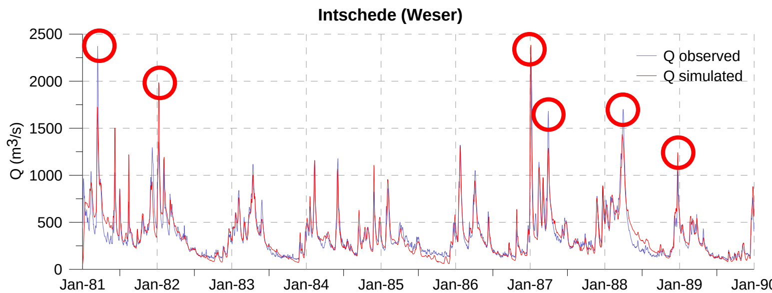
Step 2: modelling hydrological processes for each realisation using SWIM (for ~5000 river reaches/ sections)

Step 3: calculation of extreme value statistics (reference period) for each river reach (General Pareto Distribution GPD)

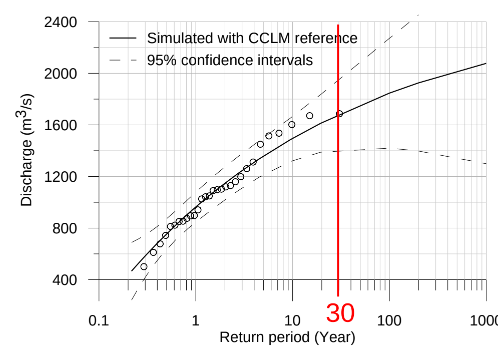
Step 4: linking runoff and damages using GPD, calculate flood damages for each river reach and scenario day



Downscaling and hydrological modelling (~5000 river sections)



Calculation of extreme value distributions



General Pareto Distribution:

$$F_u(x) \approx G(x;\tilde{\sigma},\xi,u) = 1 - \left[1 + \frac{\xi(x-u)}{\tilde{\sigma}}\right]^{-1/\xi}$$

Developed for return interval *T*:

$$T = \frac{\sqrt[\xi]{\dfrac{q-u}{\tilde{\sigma}} \cdot \xi + 1}}{n_u \cdot \Pr(x > u)}$$

$q = runoff$

$u = threshold$

$\xi, \sigma = parameters$

The regional climate models (RCMs)

First generation: "German" RCMs (7 scenario runs):

- REMO – model domain Central Europe, grid size 10 km, szenarios A1B, A2 and B1 with one realization each
- CCLM – model domain Europe, grid size ~18 km, szenarios A1B and B1 with two realizations each

Second generation: SRES A1b, 6 GCMs driving 8 RCMs (14 runs)

- Model domain Europe, 25 km grid size (EU project ENSEMBLES)

Third generation: CORDEX RCP8.5, 5 GCMs driving 6 RCMs (15 runs)

- Model domain Europe, 25 km grid size
- 11 scenario runs, 4 are additionally bias corrected (EU project IMPACT2C)

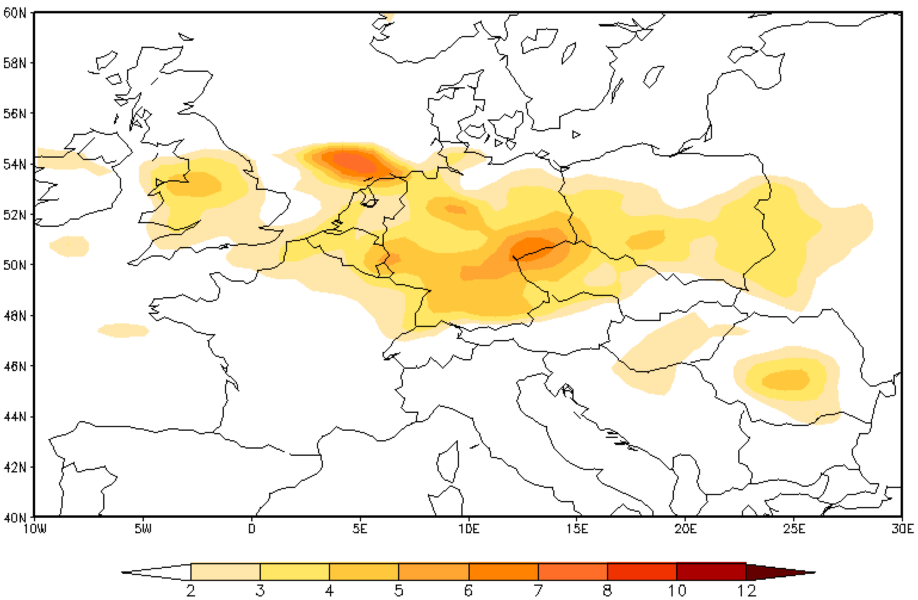
Second generation: SRES A1b regional climate model input (ENSEMBLES project)

	A1B	*Institute GCM*	HC HadCM3 Q0	HC HadCM3 Q3	HC HadCM3 Q16	MPI-MET ECHAM5 r3	CNRM Arpege	UIB BCM
Institute	*RCM*	*Resolution*						
C4I	RCA3	25 km			1951-2100			
DMI	HIRHAM5	25 km				1951-2100	1951-2100	1961-2099
ETHZ	CLM3.21	25 km	1951-2100					
HC	HadRM3 Q0	25km	1951-2100					
	HadRM3 Q3	25km		1951-2100				
	HadRM3 Q16	25km			1951-2100			
ICTP	REGCM3	25 km				1951-2100		
KNMI	RACMO2	25 km				1950-2100		
MPI	M-REMO	25km	1951-2100					
SMHI	RCA3	25km		1951-2100		1950-2100		1961-2100

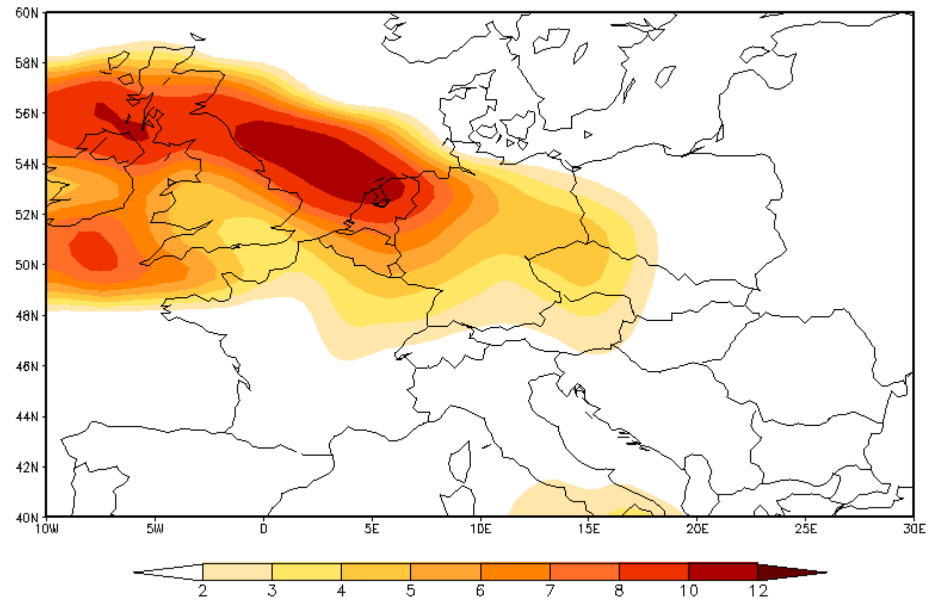
Ensembles: EU FP7 project, 14 runs selected

Storms observed and projected

The strongest strom oberved: Kyrill



Possible storm in future: EH5_1: 2079-01



Storm intensity (wind speed)

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Donat et al. 2011

SWIM vs. SWAT

Are there many differences?

- **There are some, but… (SWIM is based on SWAT'94 & MATSALU)**
- **Same model structure**
- **Basic assumptions and equations comparable**

Some specific functionalities

- **Wetlands**
- **Dams and reservoirs**
- **Agriculture (Irrigation)**
- **…**

SWAT more user-friendly…

SWIM rather "pure" scientific tool…

- Krysandova V, Hattermann FF, Huang S, Hesse C, Vetter V, Liersch S, Koch H, Kundzewicz Z (2015): *Modelling climate and land-use change impacts with SWIM: lessons learnt from multiple applications*. Hydrological Sciences Journal.

Data – da

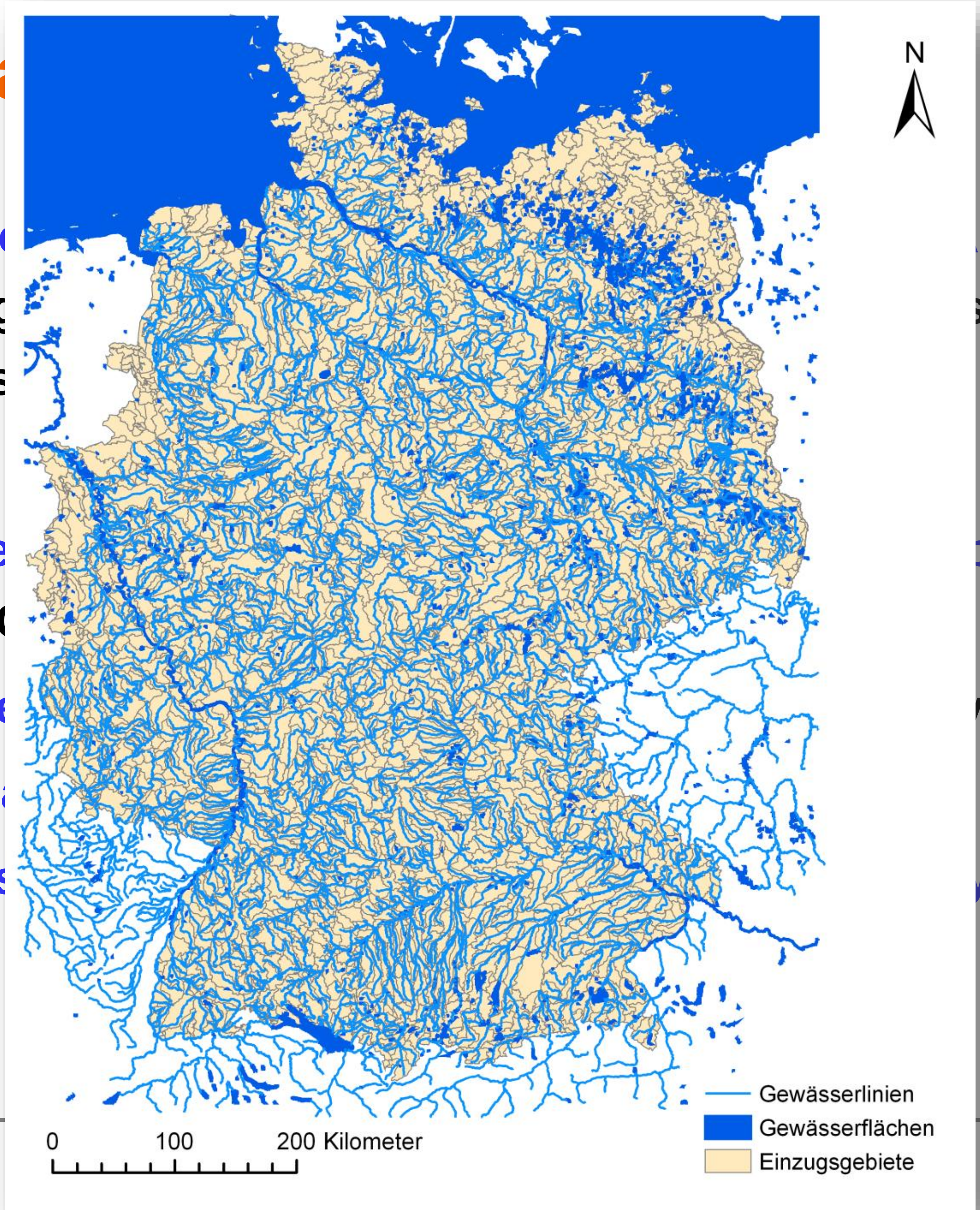
Damage func ... ssociatin
(including ... s (Munich
Re, Swiss

One damage ... code
zones in (

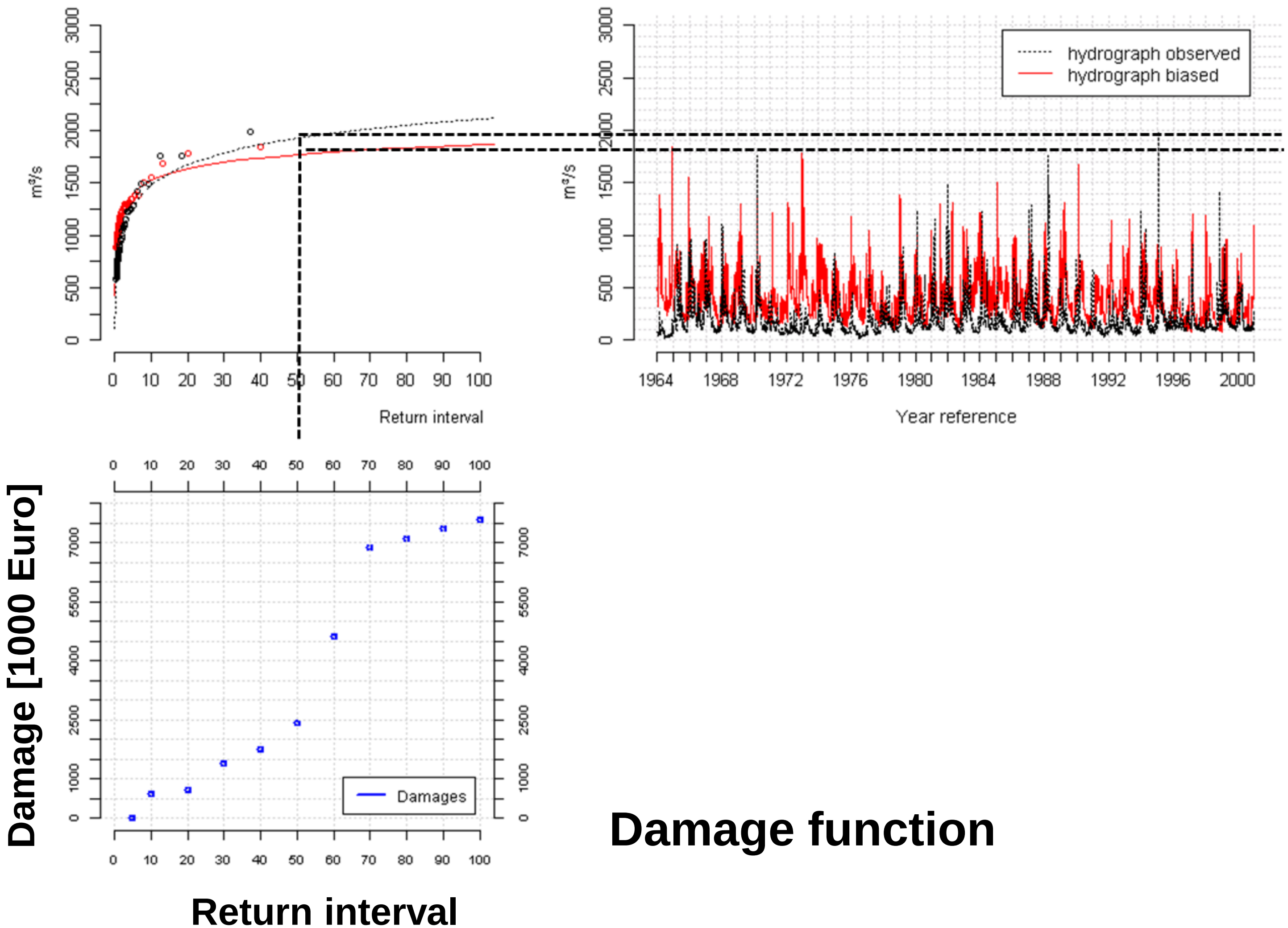
Linked to the ... y

Considered a

Average loss ... year



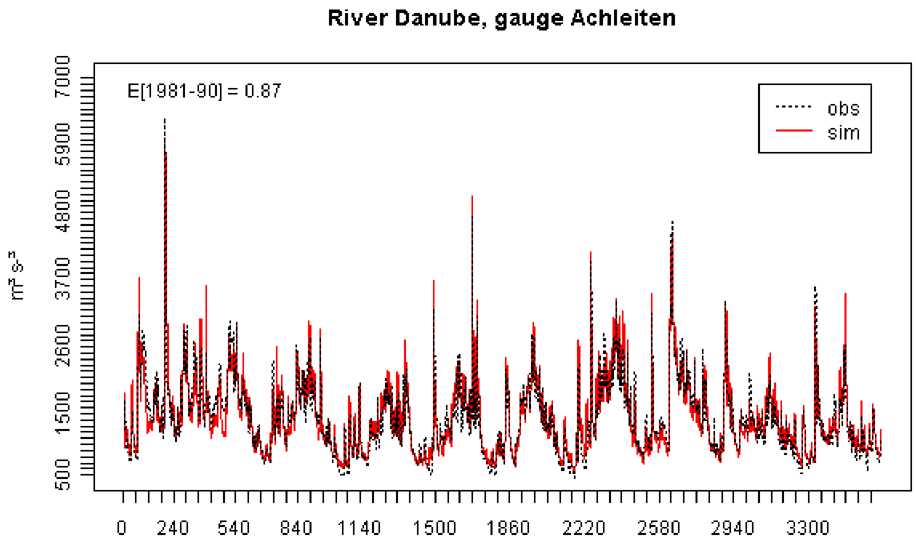
Bias correction

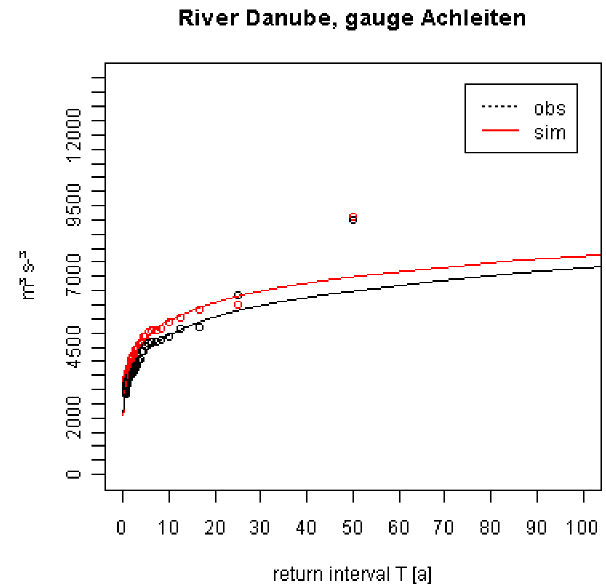


Outline

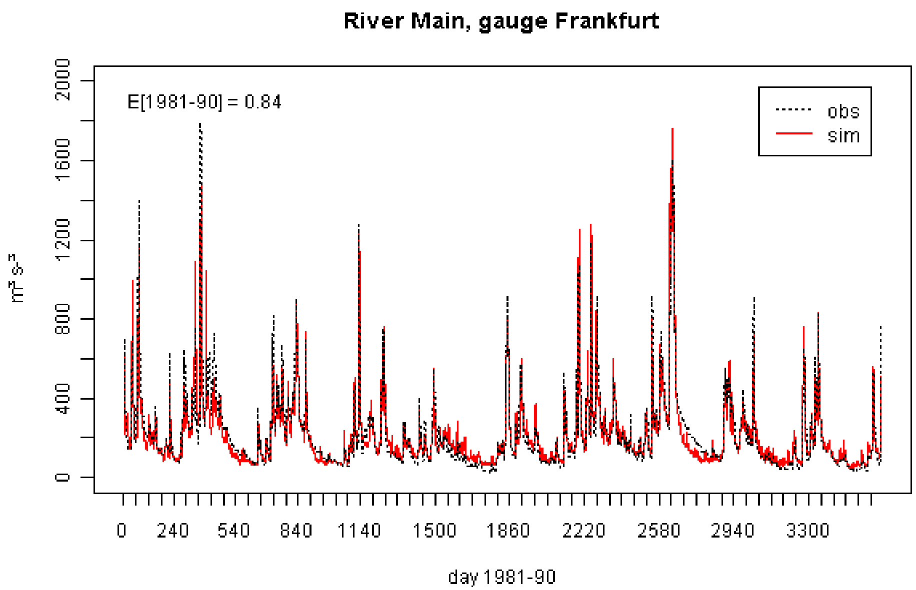
- **Model calibration**

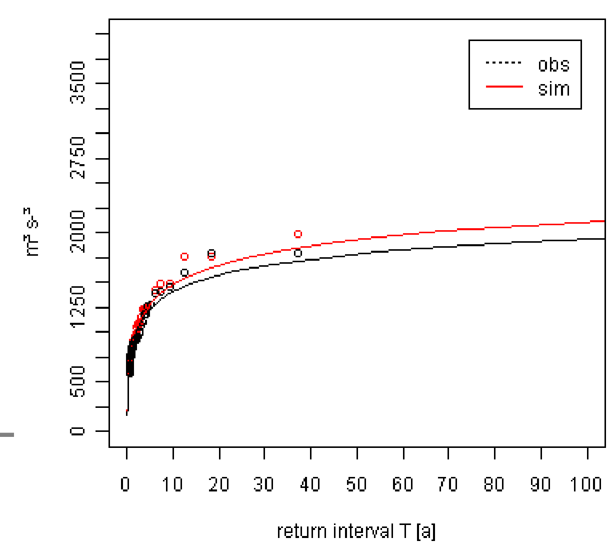
Calibration and validation using observed climate data





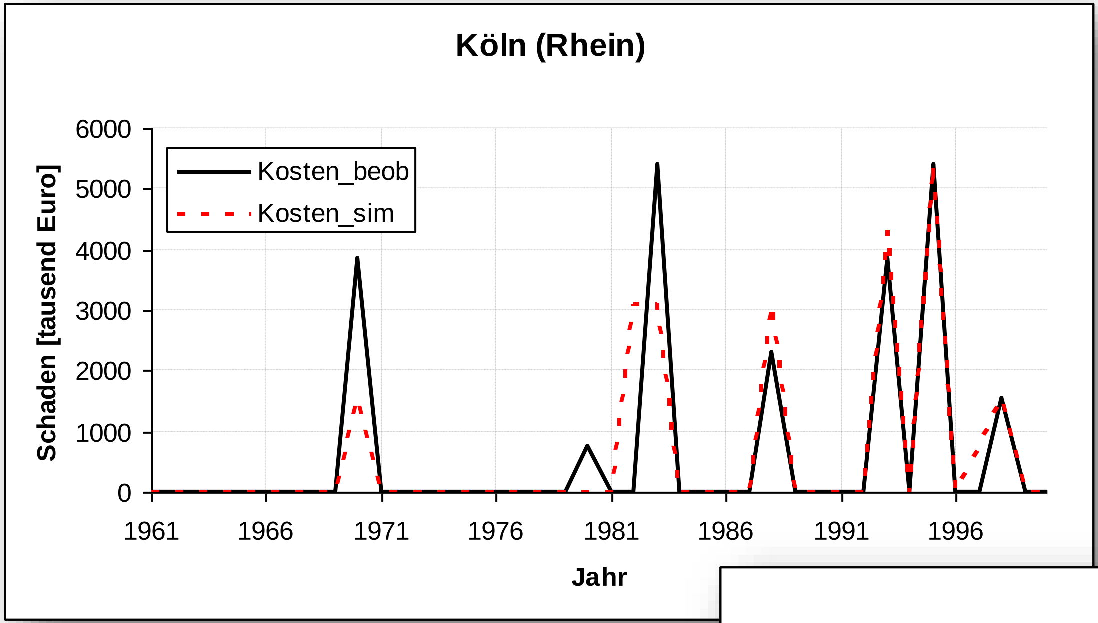
Danube

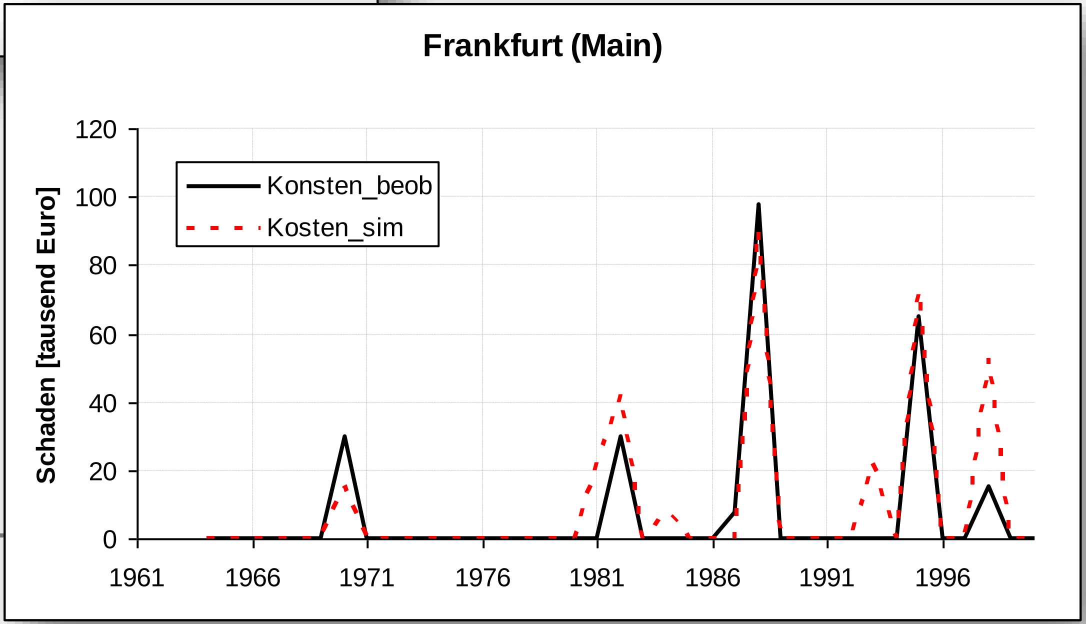




Rhine

Flood damages for specific river reaches – Rhine at Cologne and Main at Frankfurt





Losses calculated via a) observed runoff, flood statistics and damage funcitons and b) simulated runoff …

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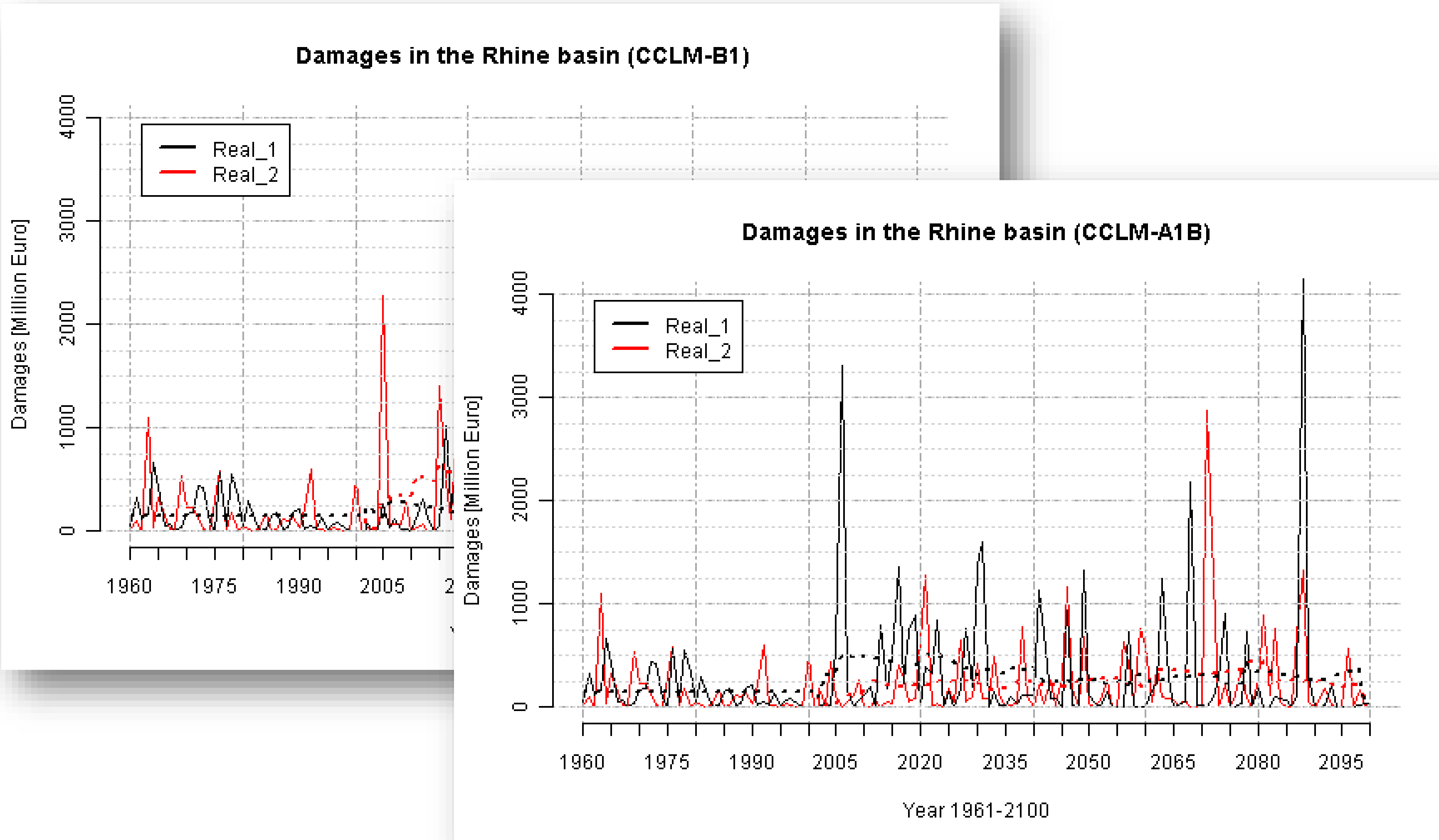
Outline

- **Scenario results**

Results: Flood damages in the Rhine basin under climate change



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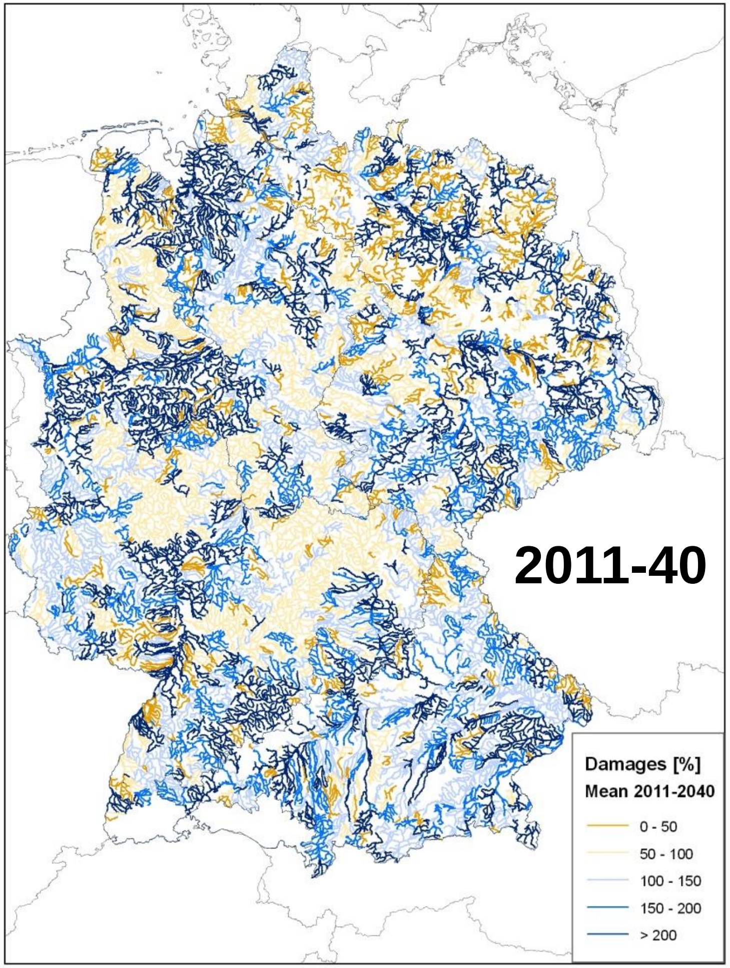
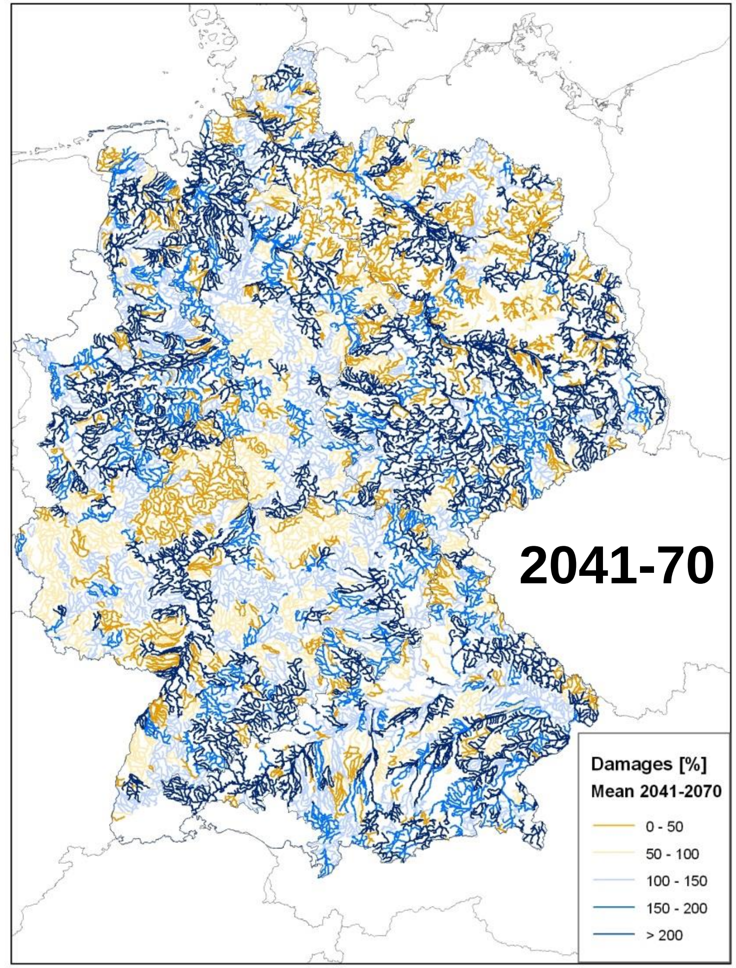
Source of damage functions: German Insurance Association (GDV), modelled at PIK, Hattermann et al. 2014

Maps of the flood-related damages under scenario conditions





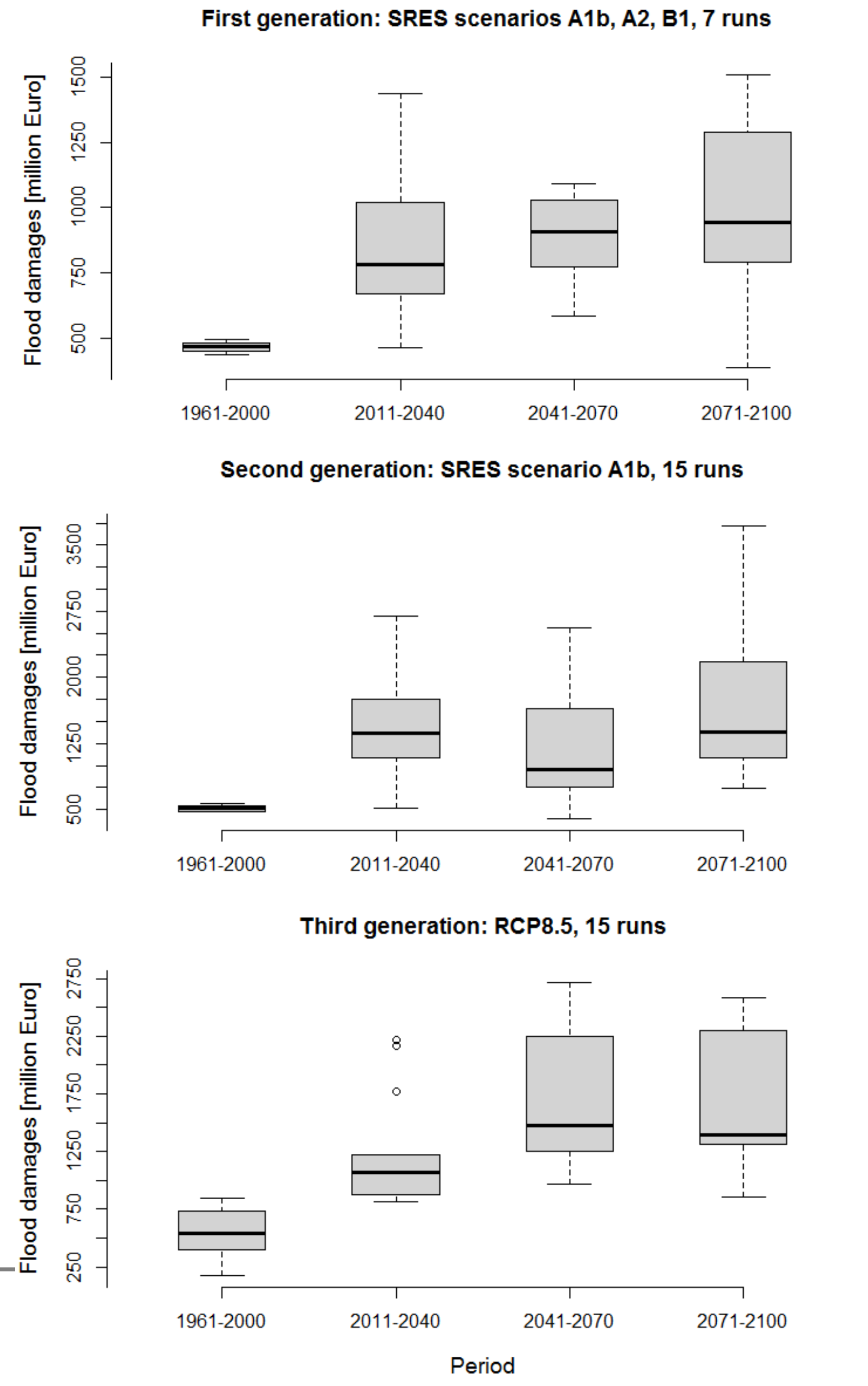
Source of damage functions: German Insurance Association (GDV), modelled at PIK, Hattermann et al. 2014

Cumulated damages for Germany

**First generation: 1 GCM, 2 RCMs,
3 SRES scenario: A1b, A2, B1**

**Second generation: 6 GCM, 8 RCMs,
1 SRES scenario: A1b**

**Third generation: 5 GCM, 6 RCMs,
1 scenario: RCP8.5**



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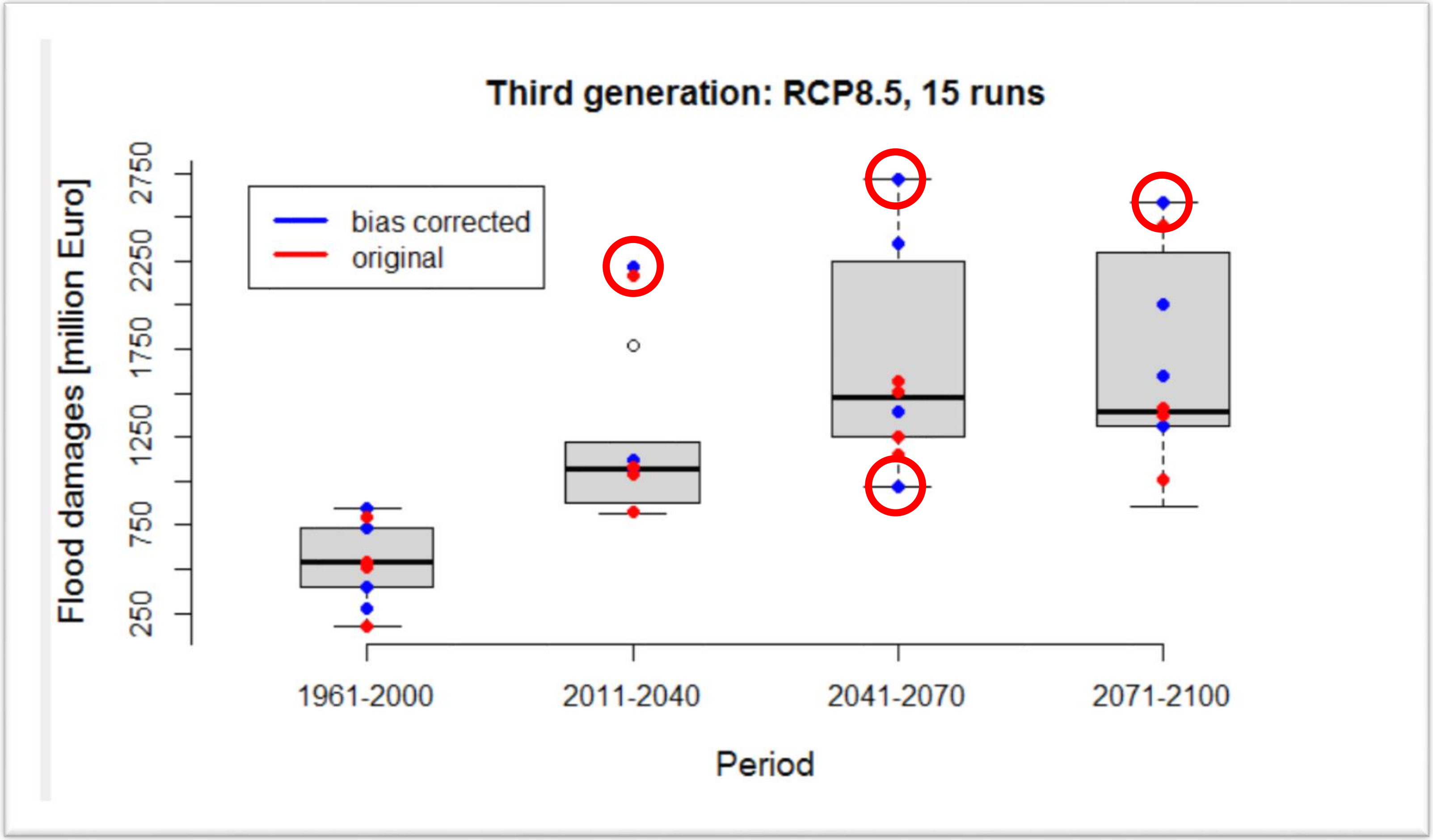
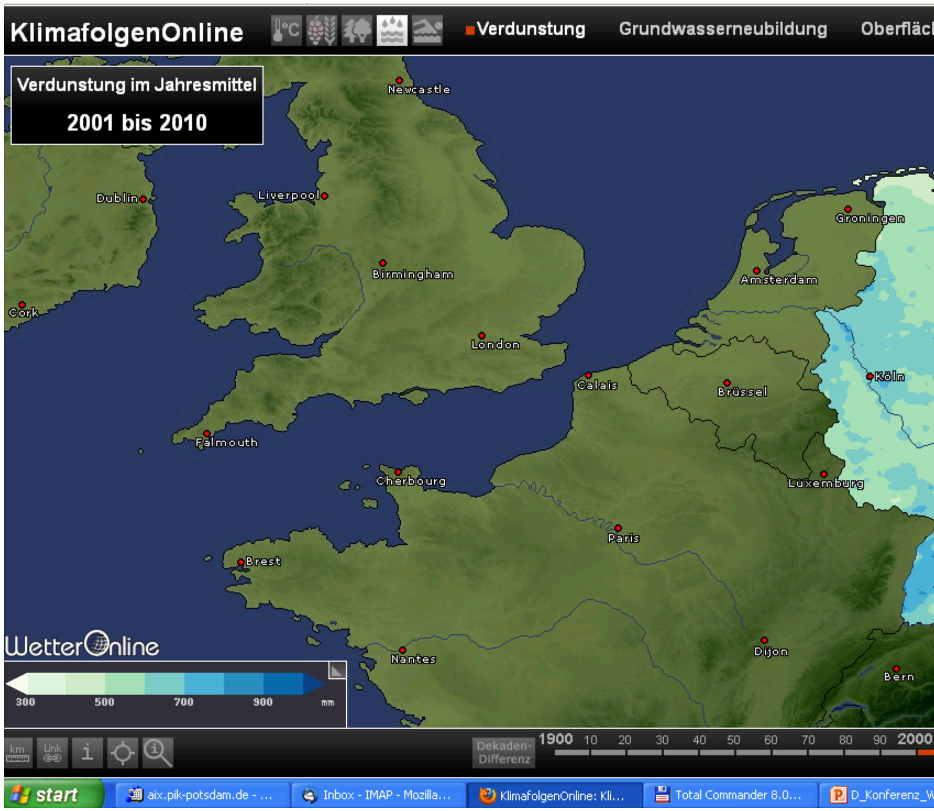
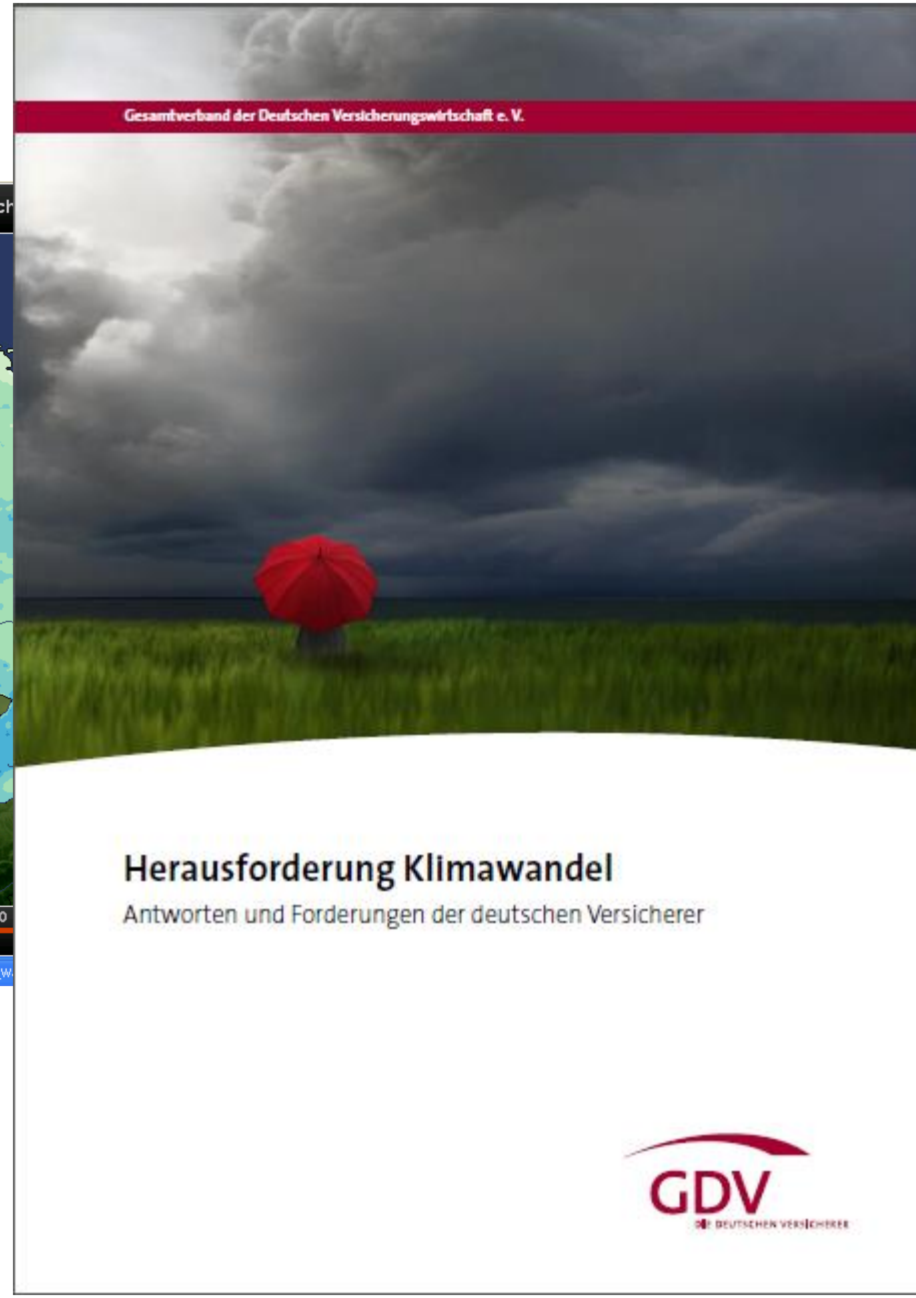
Impact of bias correction on results



Source of damage functions: German Insurance Association (GDV), modelled at PIK, Hattermann et al. 2014

Outlook Wetteronline …





http://www.gdv.de/2011/11/schadenszenarien-bis-zum-jahr-2100/

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Literature and Acknoledgmens

Hattermann FF, Huang S, Burghoff O, Willems W, Österle H, Büchner M, Kundzewicz Z (2014): ***Modelling flood damages under climate change conditions – a case study for Germany***

Nat. Hazards Earth Syst. Sci., 14, 3151–3169, 2014, www.nat-hazards-earth-syst-sci.net/14/3151/2014/, doi:10.5194/nhess-14-3151-2014

Acknoledgments

- to the German Insurance Association (GDV) for providing the damage functions and greatly supporting the study
- to the EU projects ENSEMBLES and IMPACT2C for providing the climate input data

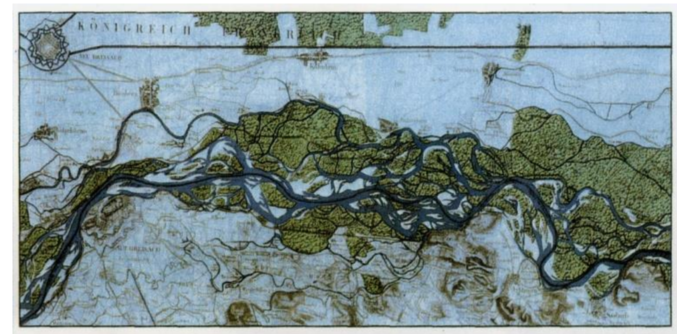
Thank you very much!

Land use and floods

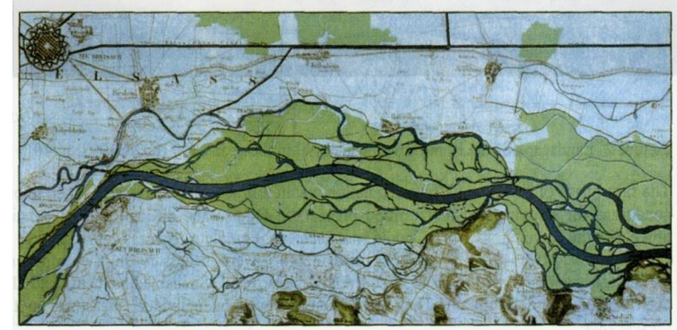
Oberrhein nördlich von Basel (Isteiner Klotz) um 1800 (Gemälde von Peter Birrmann, Kunst-museum Basel)

Wasserstraße Rhein nördlich Breisach

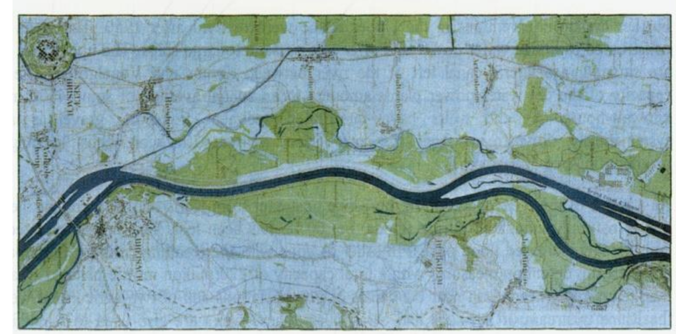
Der Oberrhein bei Breisach



1820



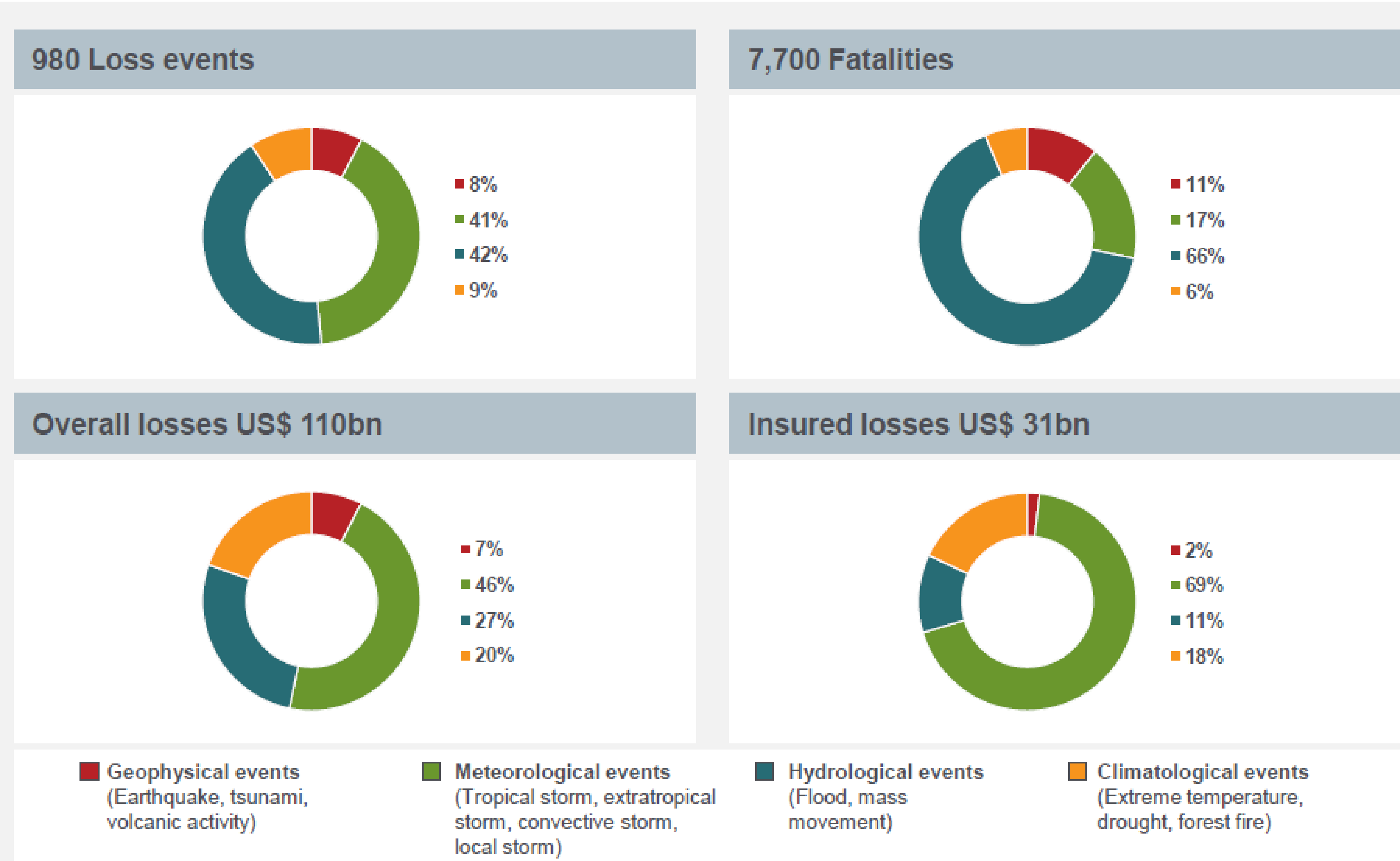
1870



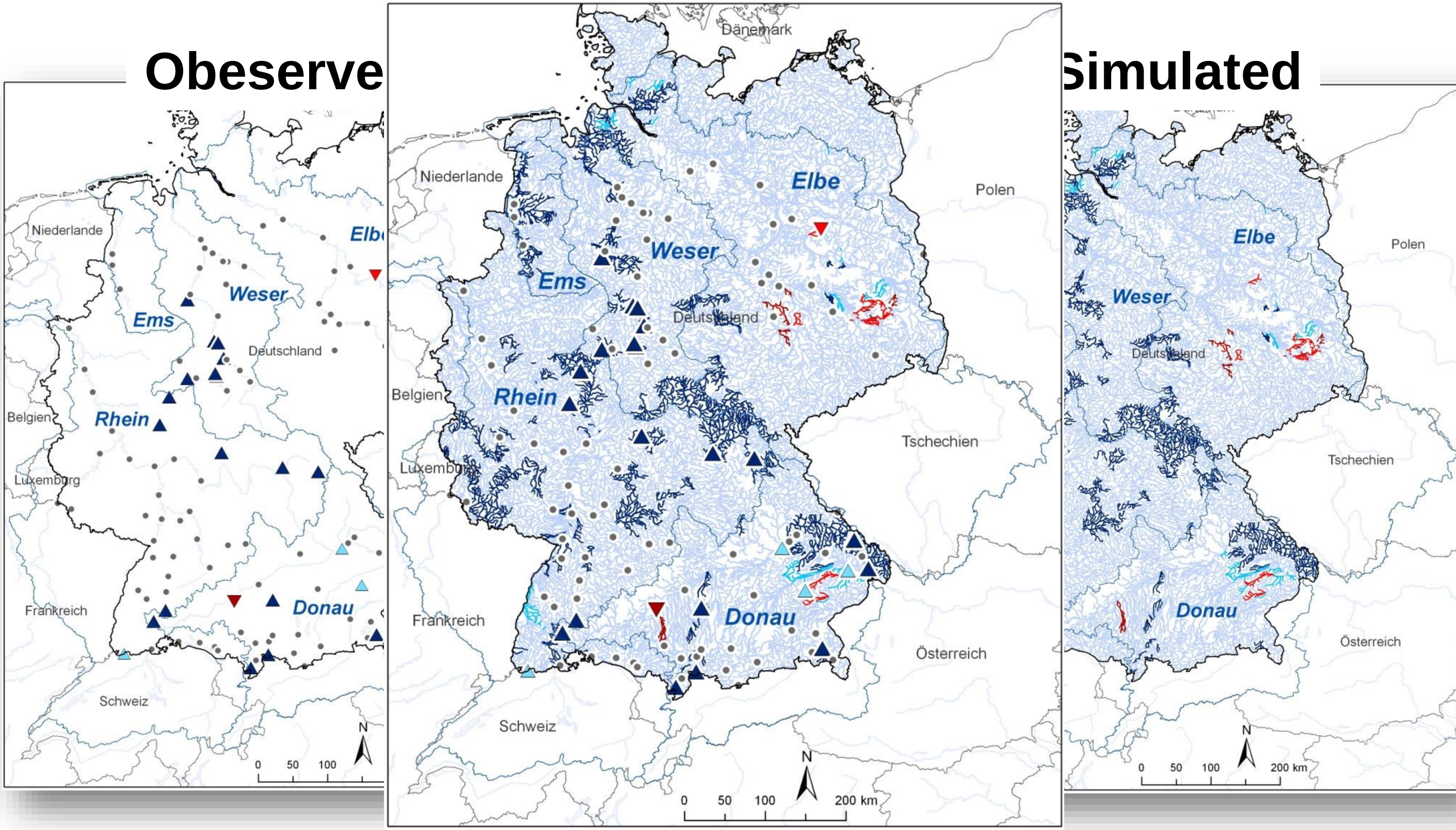
1990

Bronstert (2005)

Loss events worldwide 2013



Introduction Trend in annual flood maximum 1951-2003



Hattermann et al. 2012a&b

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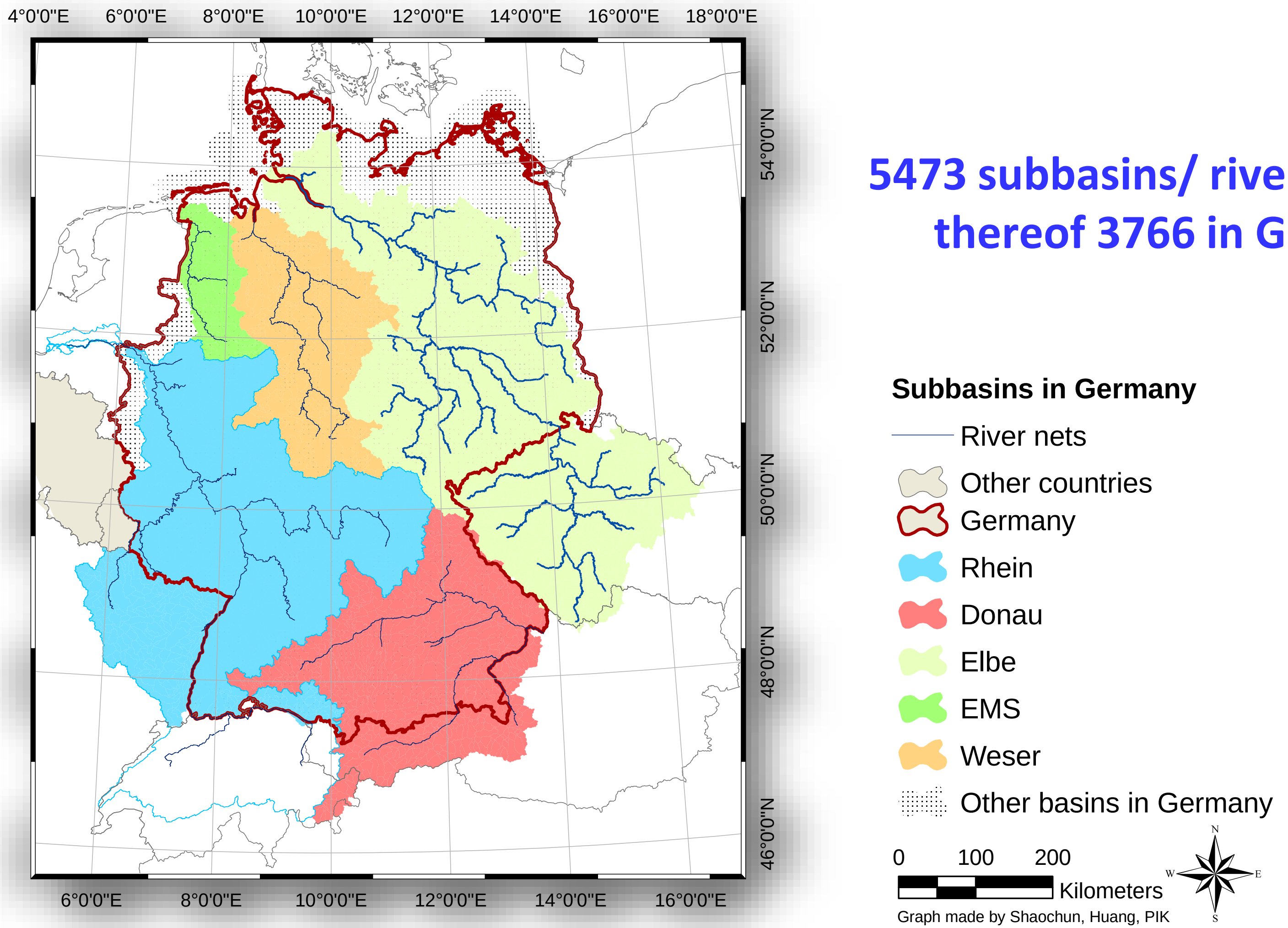
Data: Main German river basins



5473 subbasins/ river reaches, thereof 3766 in Germany

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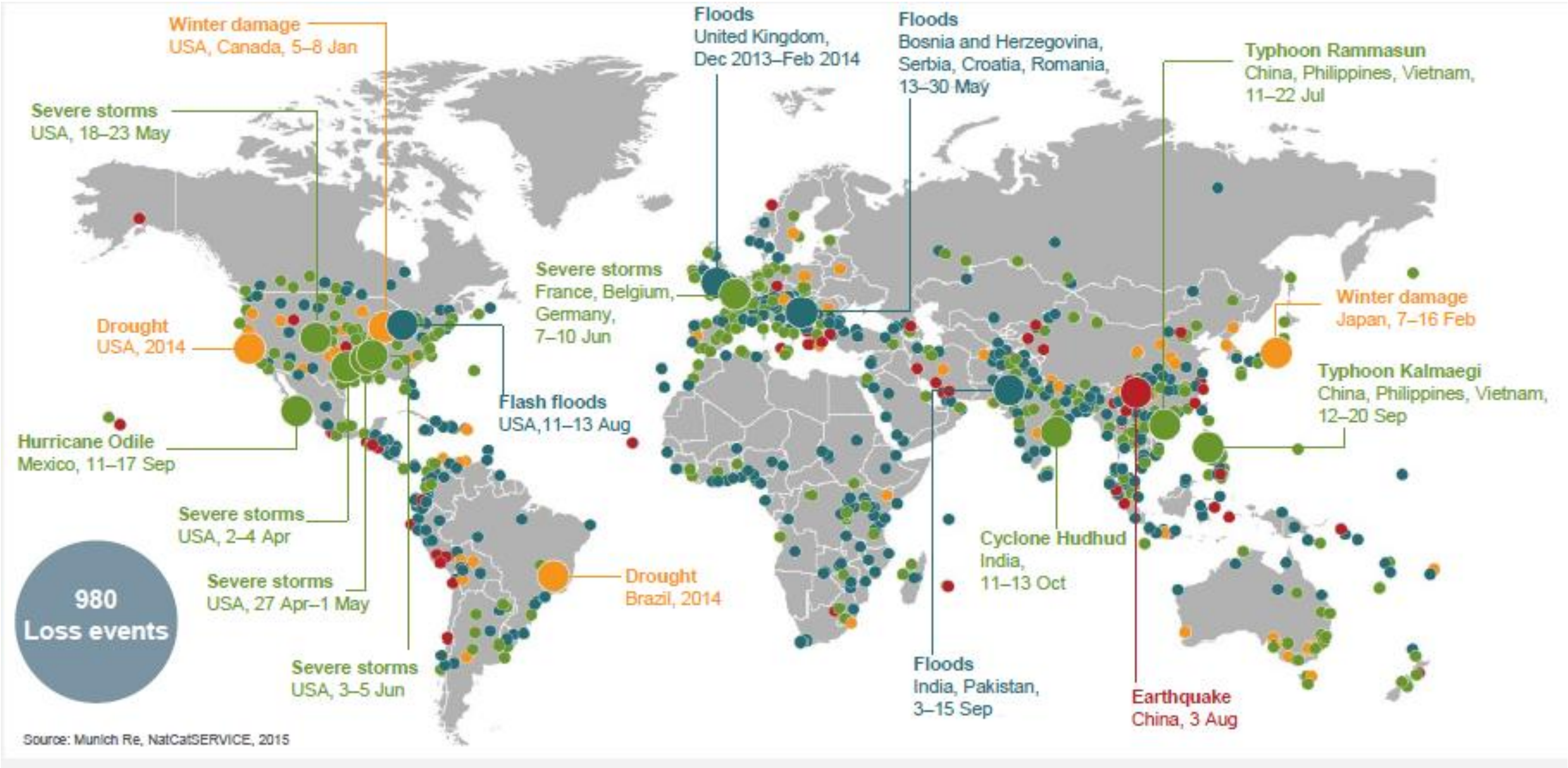
Significant floods 2014



- Natural catastrophe
- Significant events
- Geophysical event
- Meteorological event
- Hydrological event
- Climatological event

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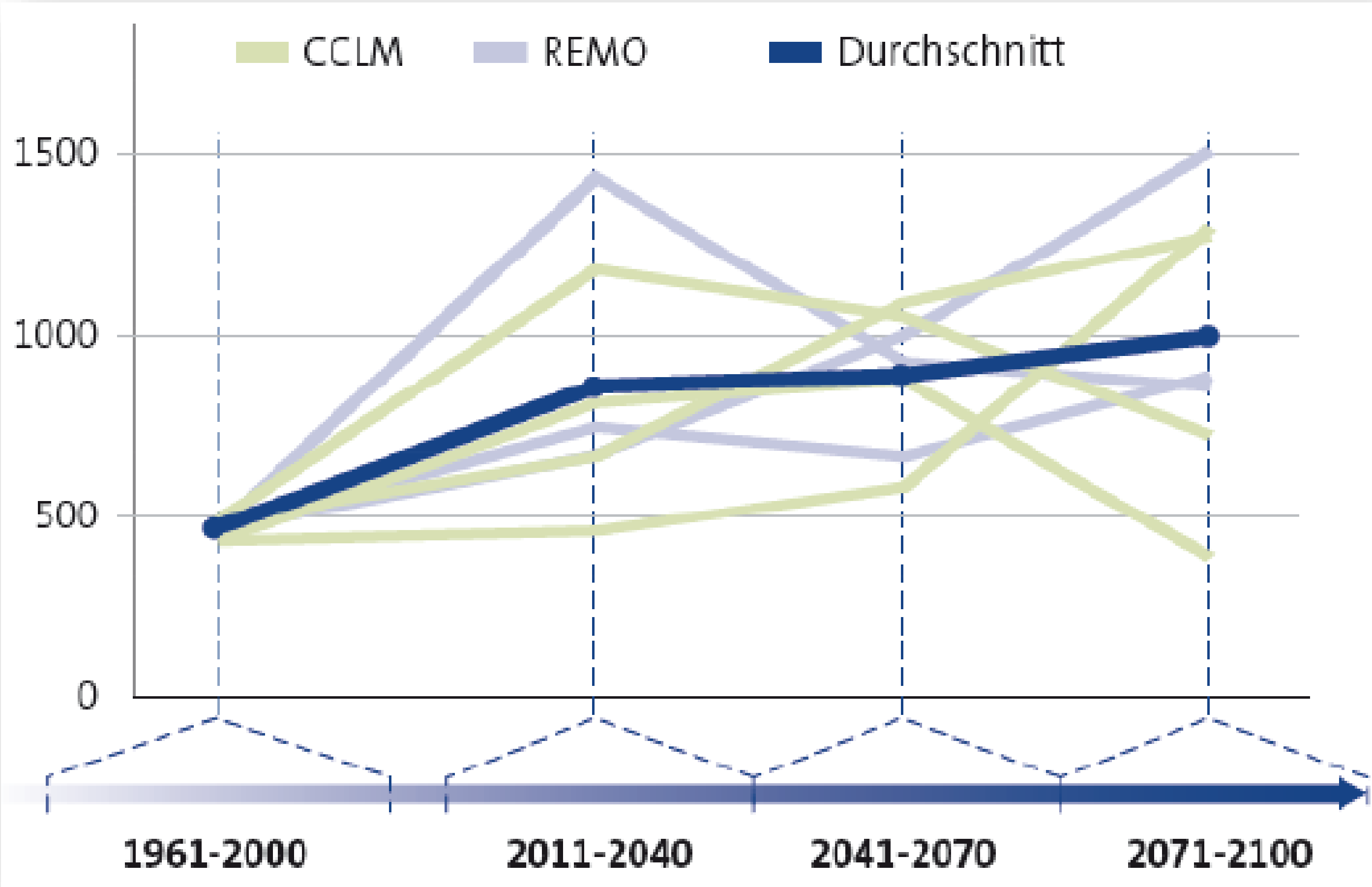
Outline

- Hydro-meteorological extremes under climate change
- Increasing flood risk in Germany
- Turn of the tide in West Africa
- Outlook

Annual losses per climate model and realization in Germany



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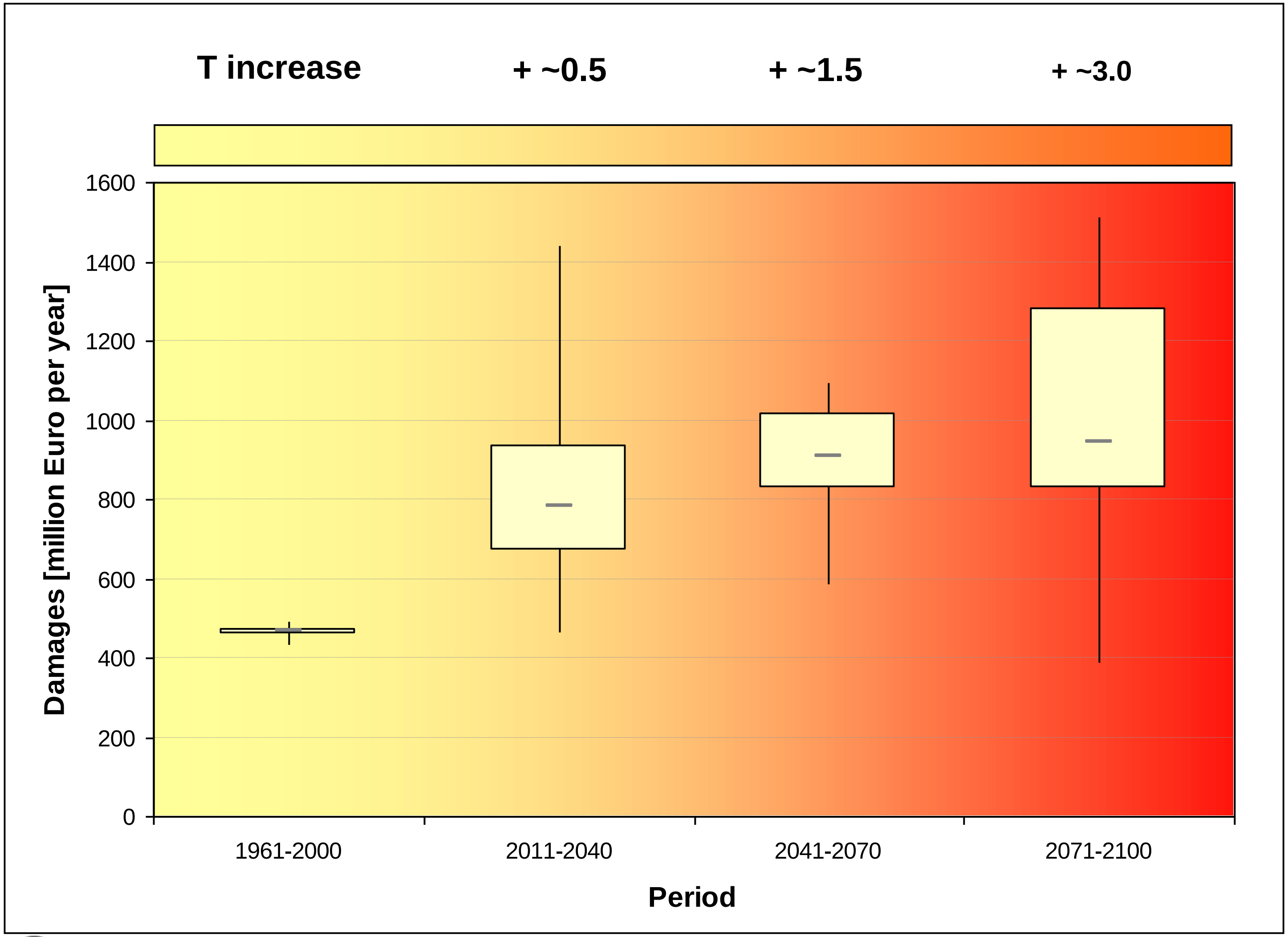
Source of damage functions: German Insurance Association (GDV), modelled at PIK, Hattermann et al. 2014

Average annual damages per period



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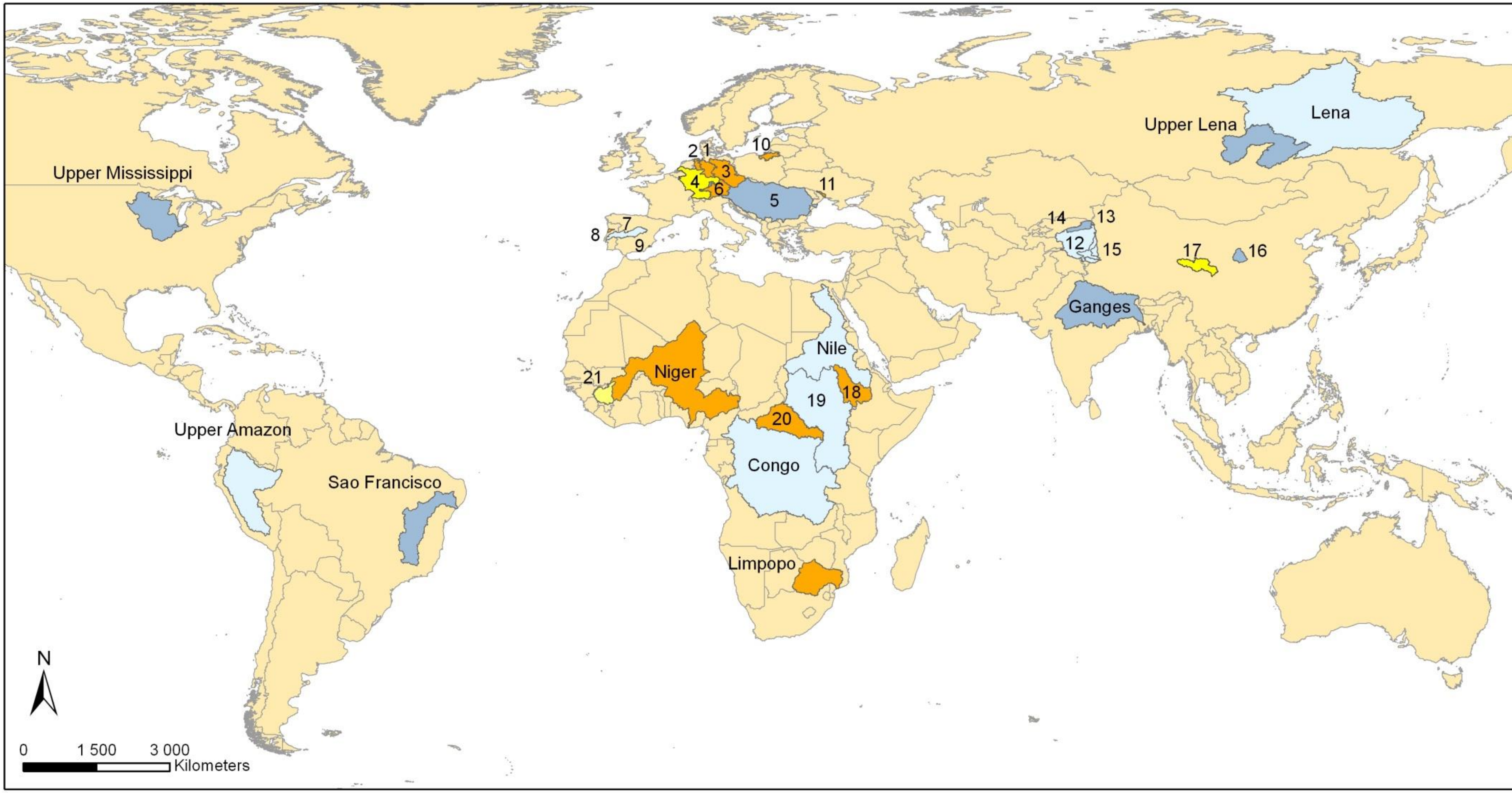
Source of damage functions: German Insurance Association (GDV), modelled at PIK, Hattermann et al. 2014

River basins under investigation – ISIMIP



Europe			Asia		Africa
1, Weser	5, Danube	9, Mar Menor	12, Tarim Headwater	15, Hotan	18, Blue Nile
2, Ems	6, Danube (upper part)	10, Vistula Lagoon	13, Tailan	16, Jinghe	19, White Nile
3, Elbe	7, Tagus	11, Tyligulskyi Liman	14, Aksu	17, Yellow river (upper part)	20, Ubangi
4, Rhine	8, Ria de Aveiro				21, Niger until Koulikouro

Modeling status

- Model Intercomparison
- Impact Study ready
- Validation ready
- Calibration in work

Valentin Aich, Bakary Koné, Eva N. Müller and Fred F. Hattermann (2014) Assessing the increasing flood risk in the Niger River: Climate change, land use change or increasing vulnerability?

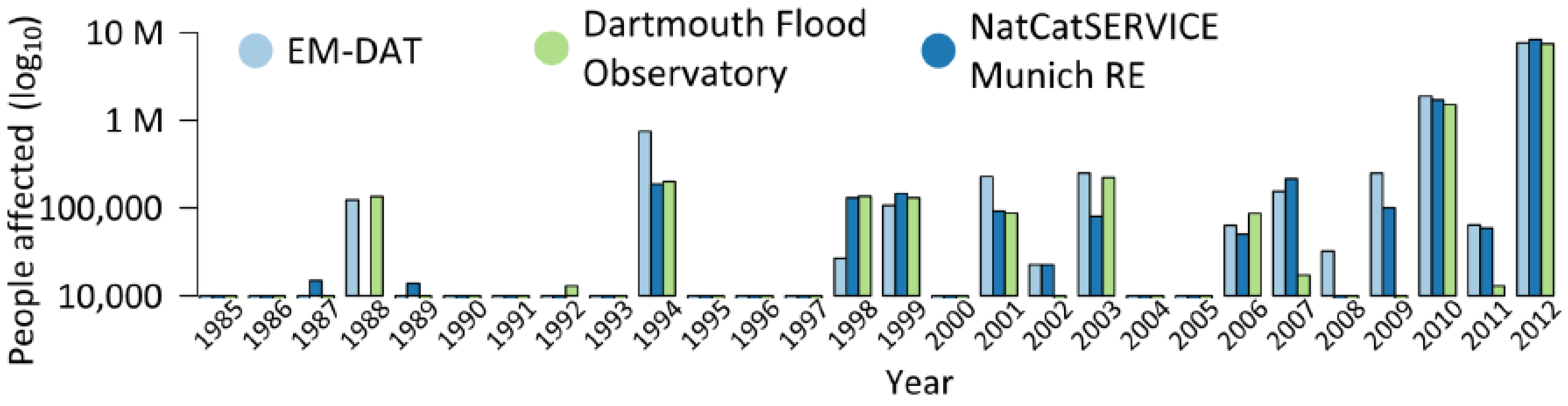
Topics of the study:

- Trends in people affected, AMAX and precipitation.
- The „Sahel Paradox“ and why there is no more paradox.
- Correlation with the Atlantic Multidecadal Oscillation (AMO).
- Non-stationary Extreme Value distribution

Methods:

- Data based attribution approach
- Simulation based attribution approach

People affected by major floods in the Niger basin

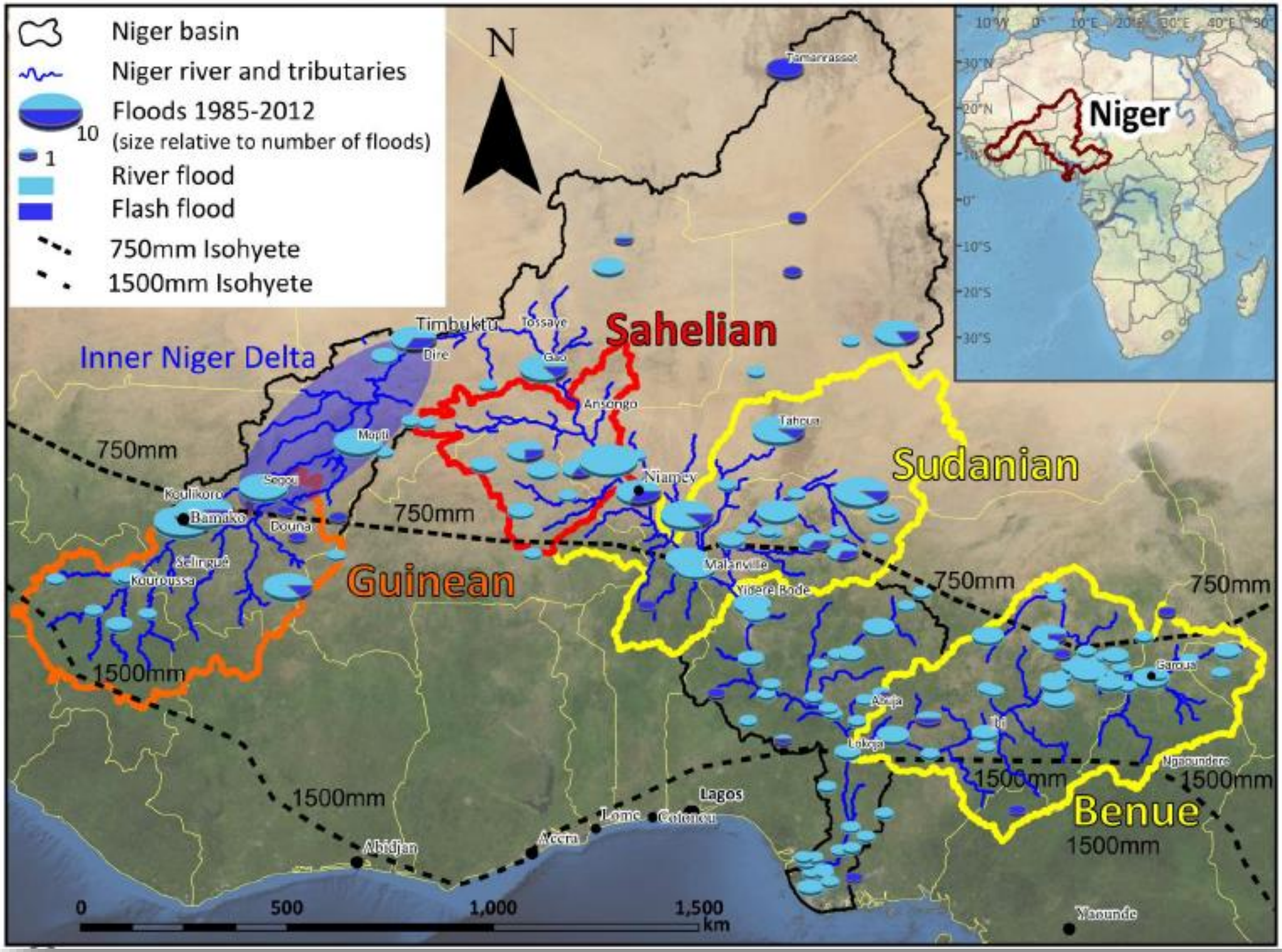


Flood risk = Values * Vulnerability * Hazard

(Kron 2005)

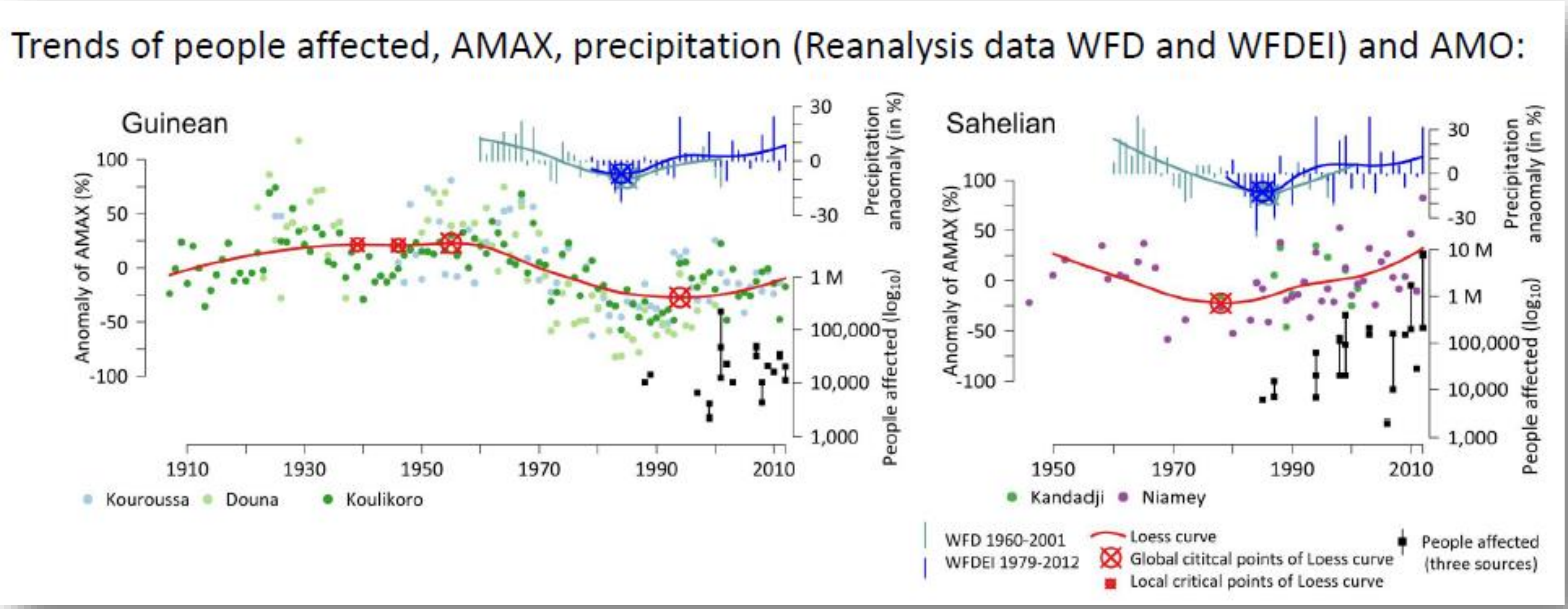
Aich et al. 2014

Flood generation areas in the Niger basin



Aich et al. 2014

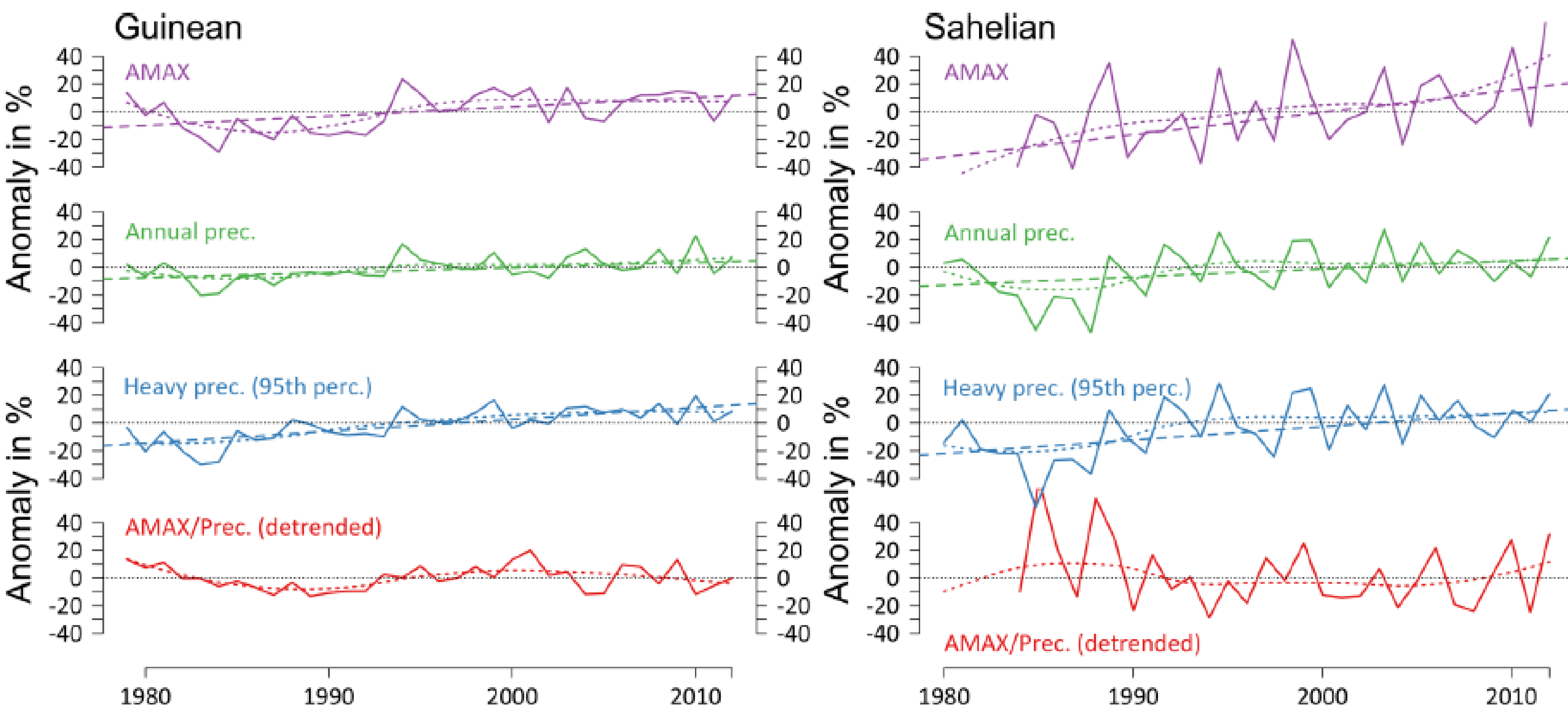
Data based trend attribution



Aich et al. 2014

Data based trend attribution

Trends in AMAX, annual prec., heavy prec. , and the runoff coefficient (AMAX/Prec):

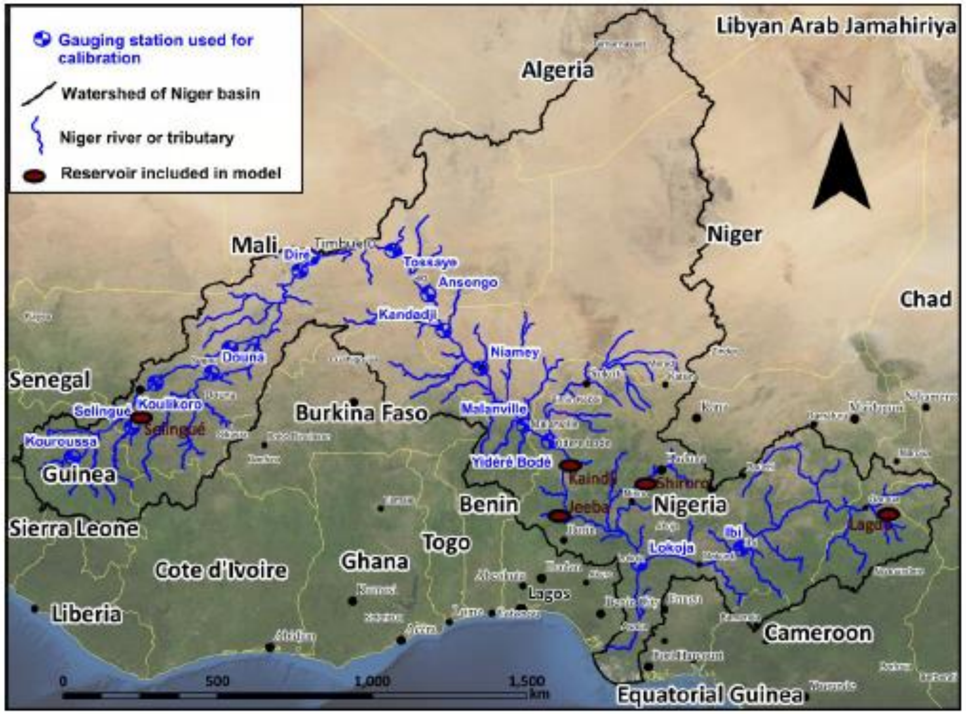


Aich et al. 2014

Model based trend attribution

SWIM set-up for the Niger basin:

- Adapted to African soils and land use
- Includes 5 major reservoirs
- Includes an inundation module for the Inner Niger Delta



Aich et al. 2014

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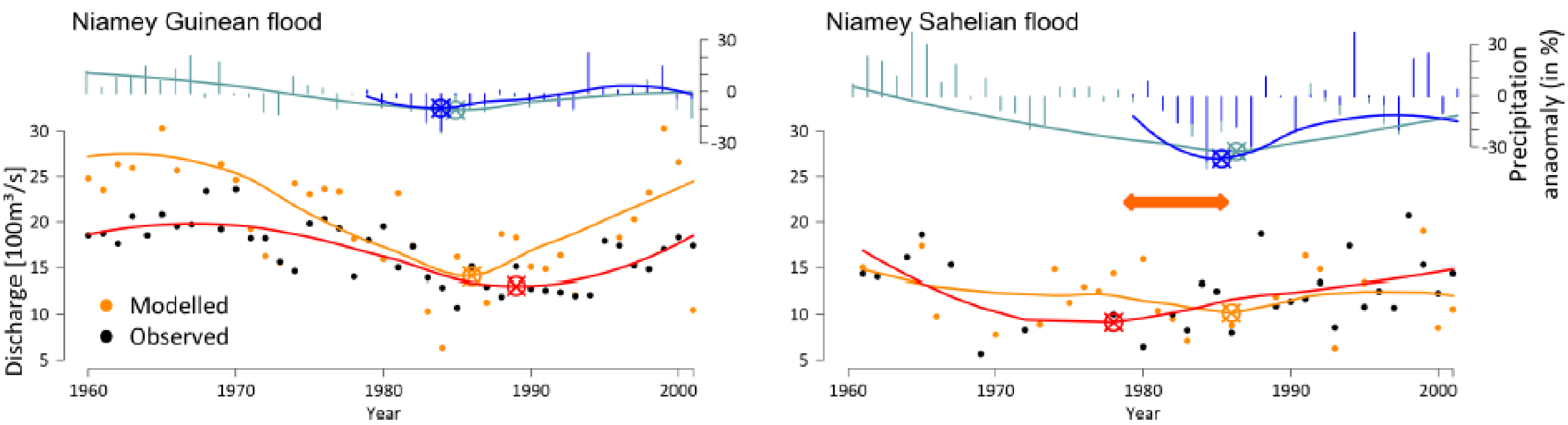
Model based trends attribution

Simulation results (driven with reanalysis data WFD) at gauge Niamey, Niger :



Conclusions for West Africa

- **Climate variability is the main driver for the increase of flood magnitude in the Niger basin.**
- **Land use change contributes in the Sahelian region to the increase of AMAX but to a minor amount.**

Aich et al. 2014

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Outline

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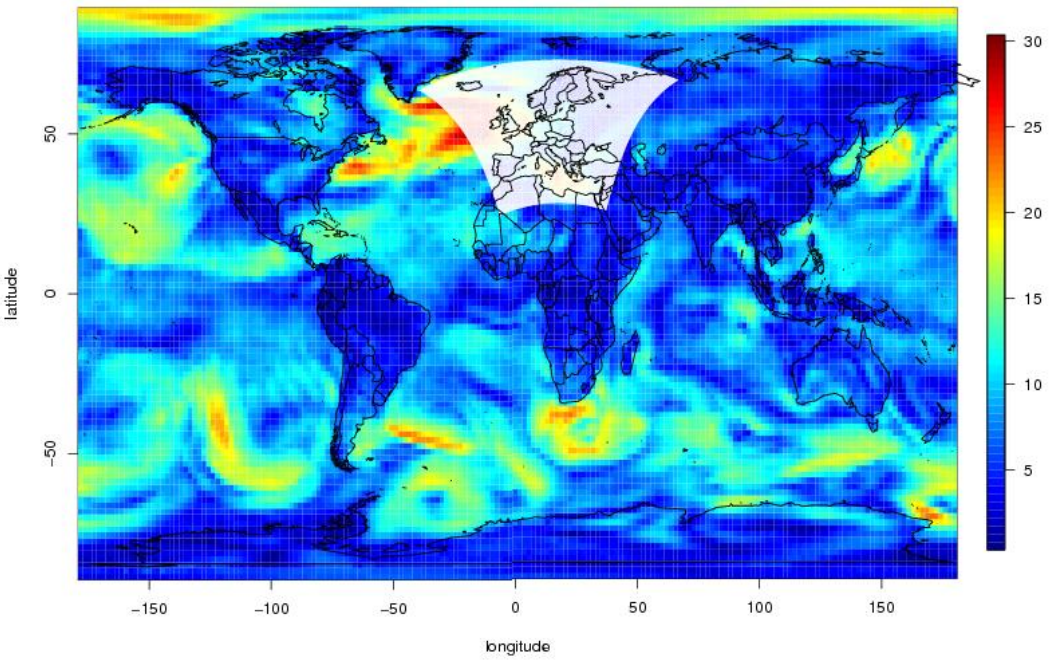
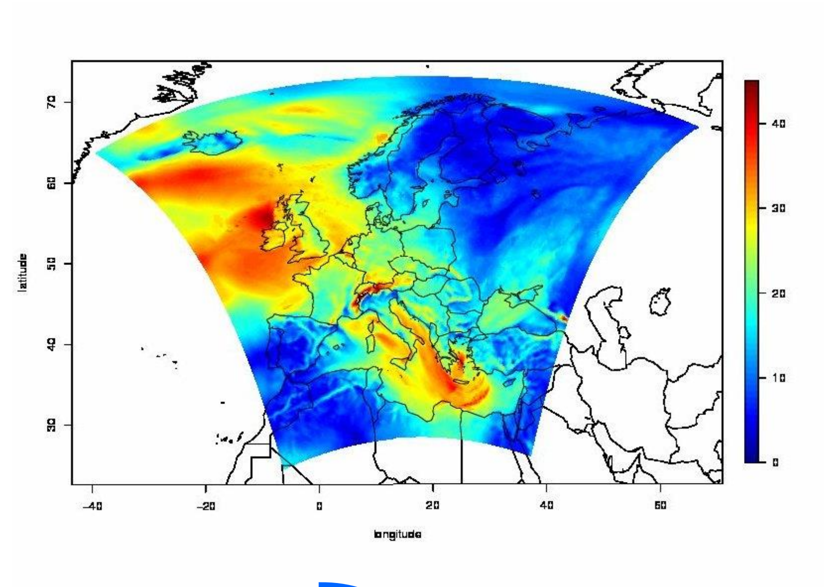
Methods: from global to regional scale

Global Cliamte model (ECHAM5)

Regional Climate Model (CCLM/ REMO)





Changes in extreme events

Planetary waves and extremes

Source: NASA

P I K

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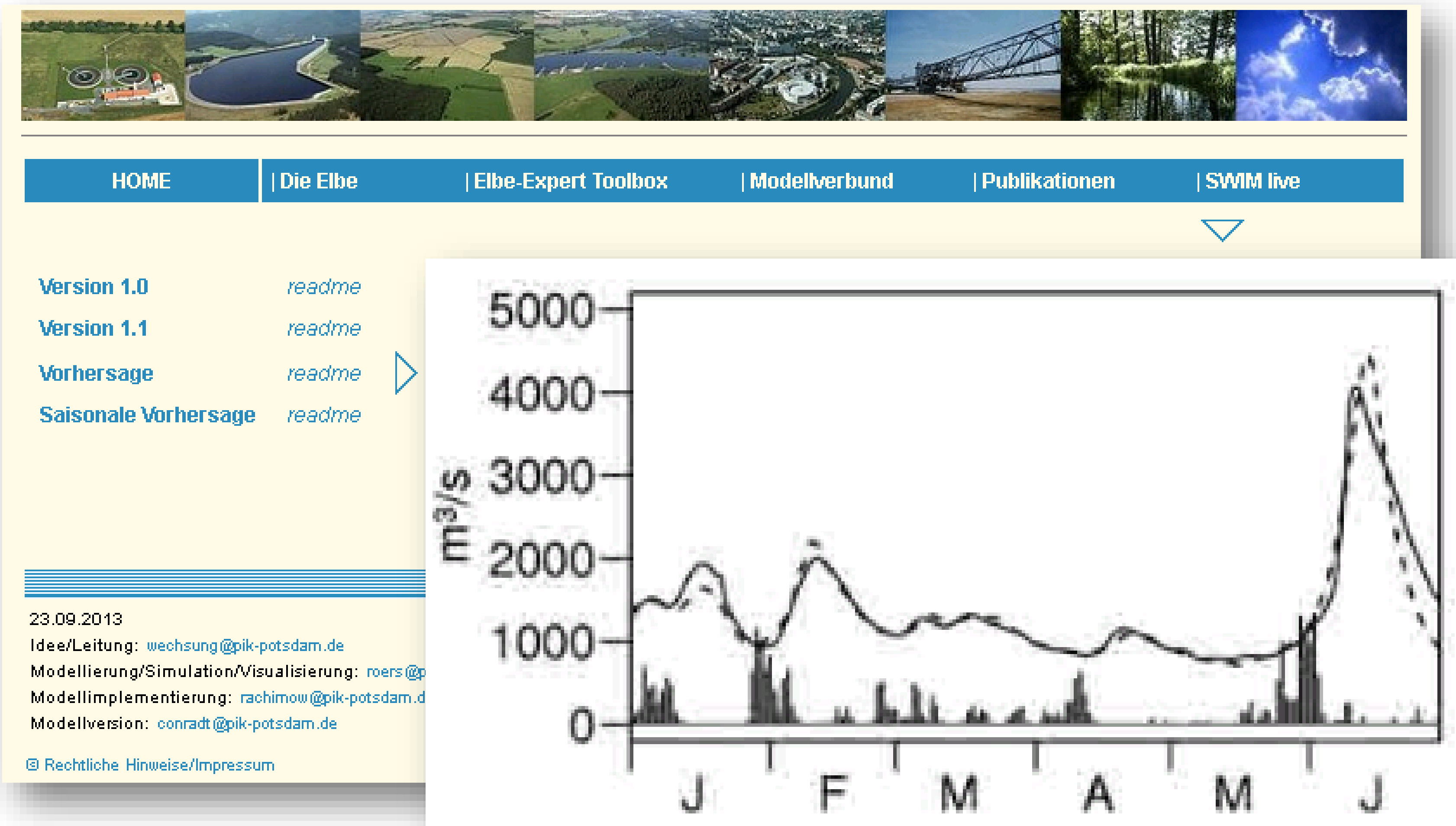
Petoukhov, V. et al. (2013) Quasi-resonant amplification of planetary waves and recent Northern Hemisphere weather extremes. PNAS 110, 5336

SWIM-Live – operational forecast

… of runoff, water availability, crop development …



Conradt et al. 2014

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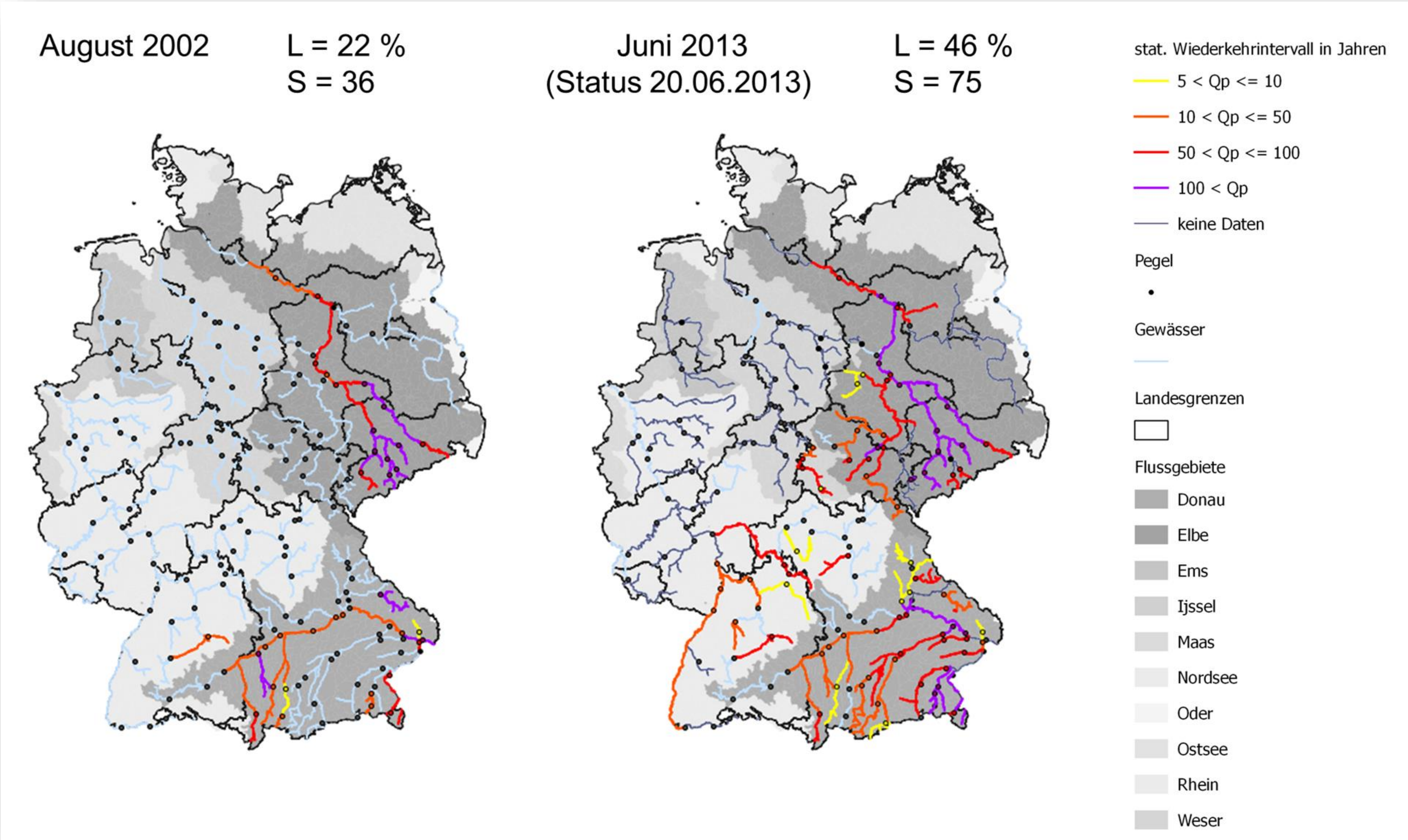
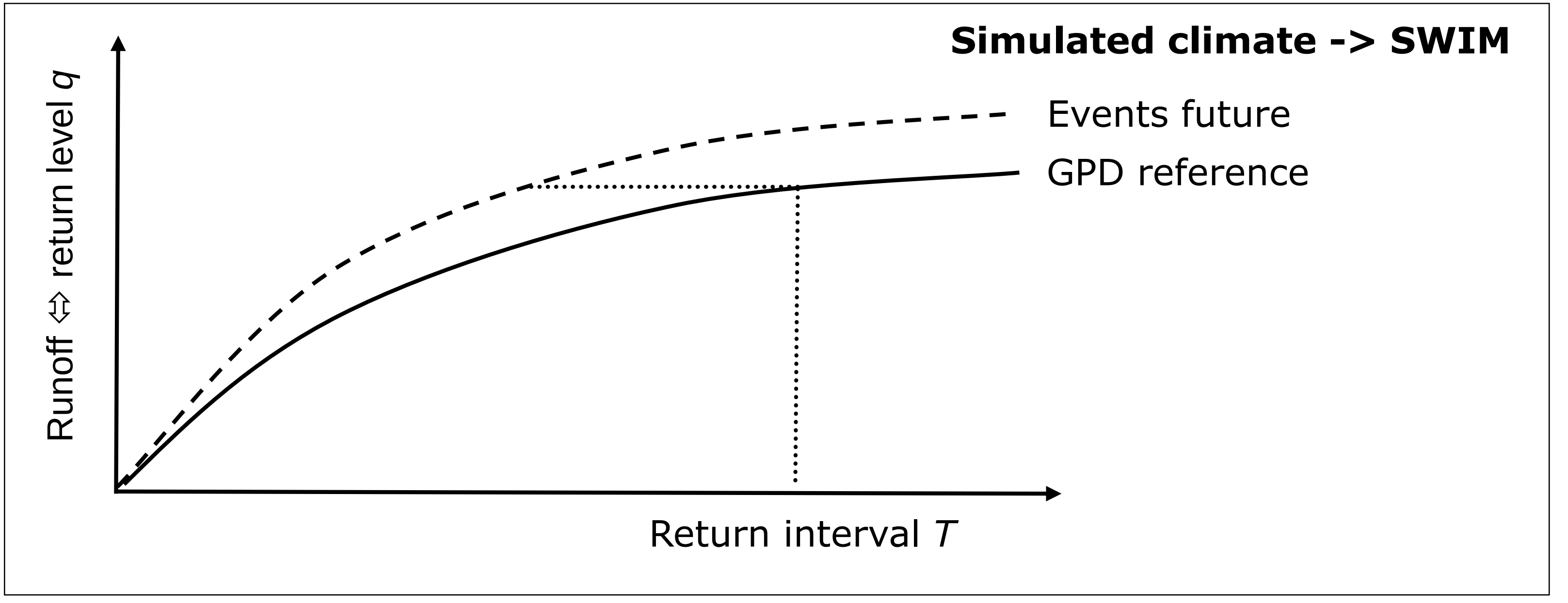
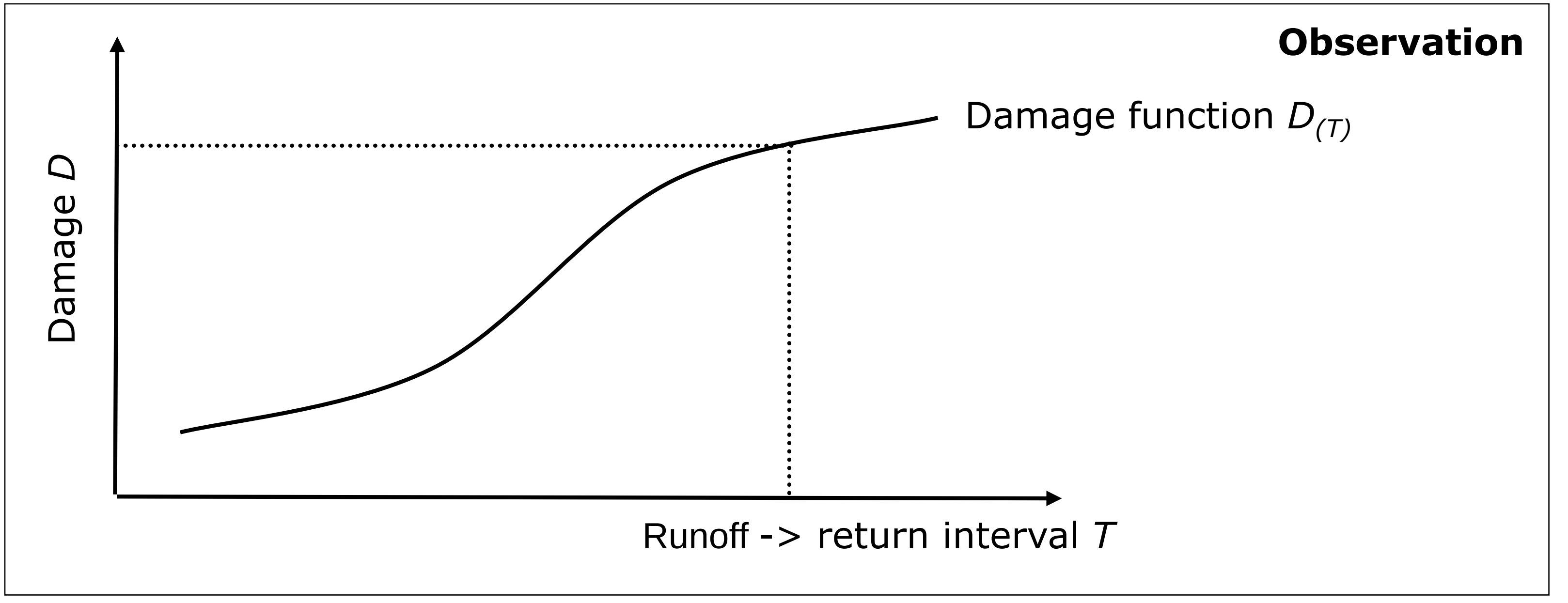
Comparison of the floods in 2002 and 2013

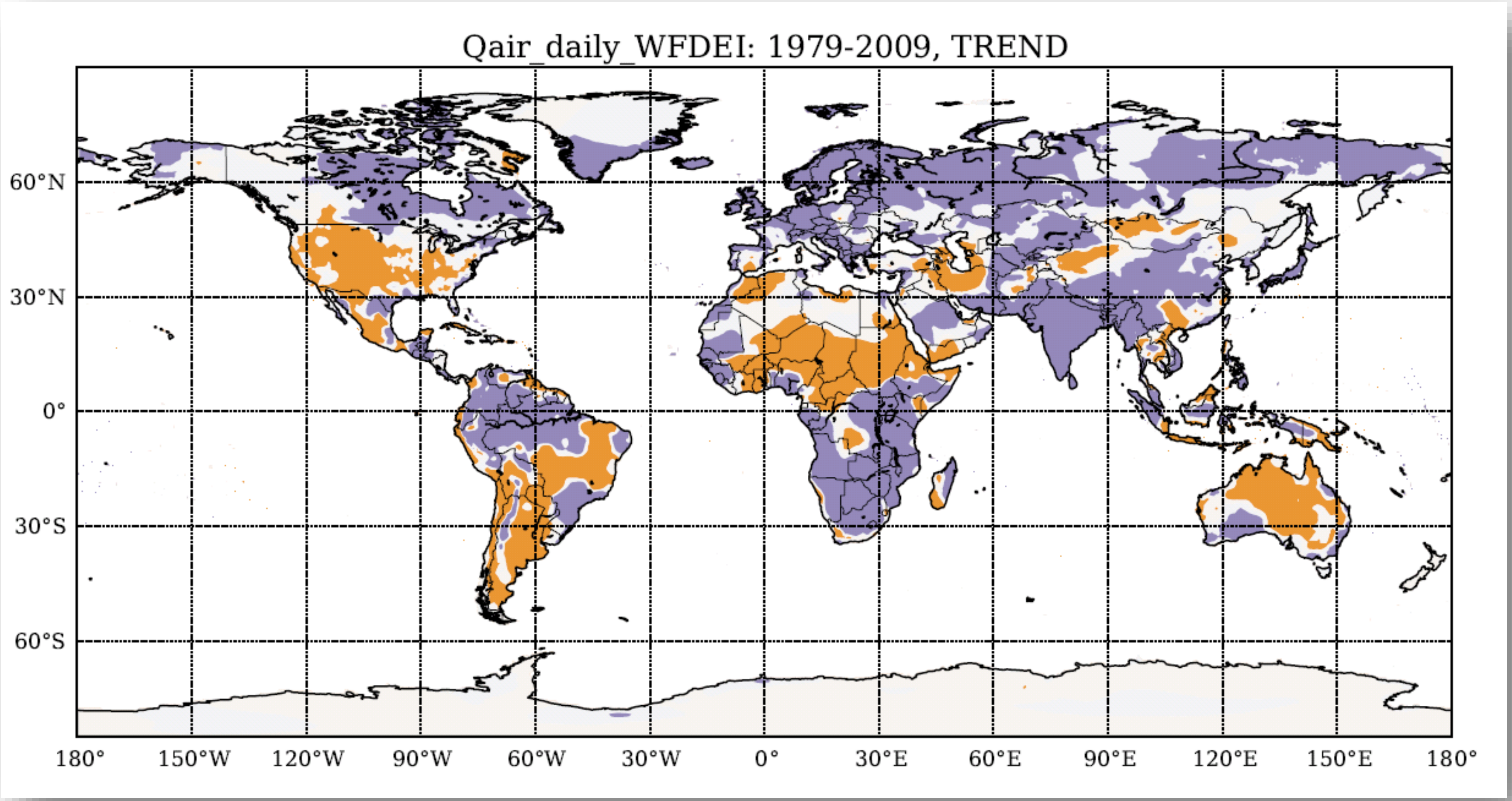


Bias correction





Trend in absolute humidity



Red: decrease, blue: increase

< -0.2g, 0.0%, >0.2g pro 30y

PIK

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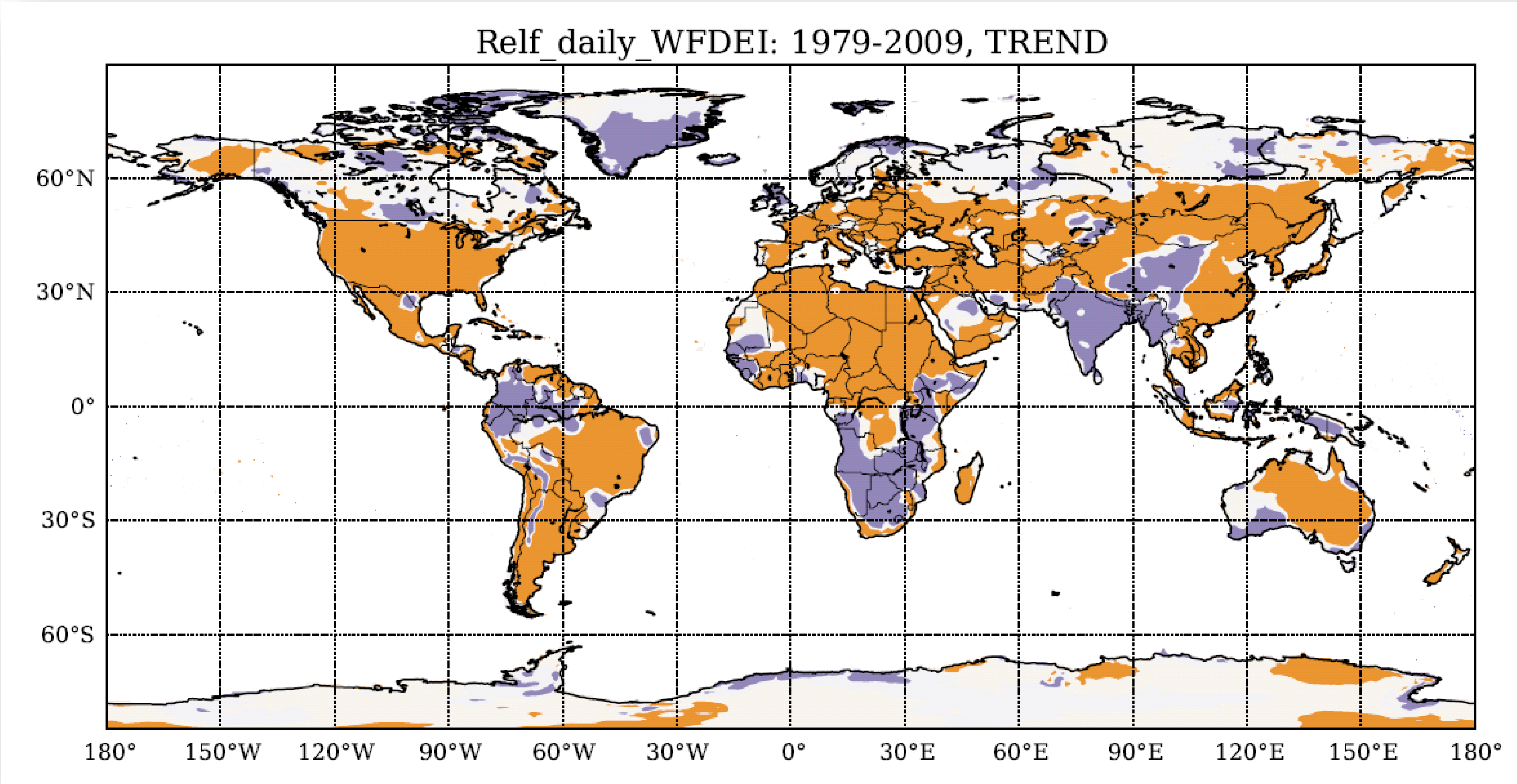
P. Hoffmann, PIK

Trend in relative humidity



Red: decrease, blue: increase
< -0.2g, 0.0%, >0.2g pro 30y

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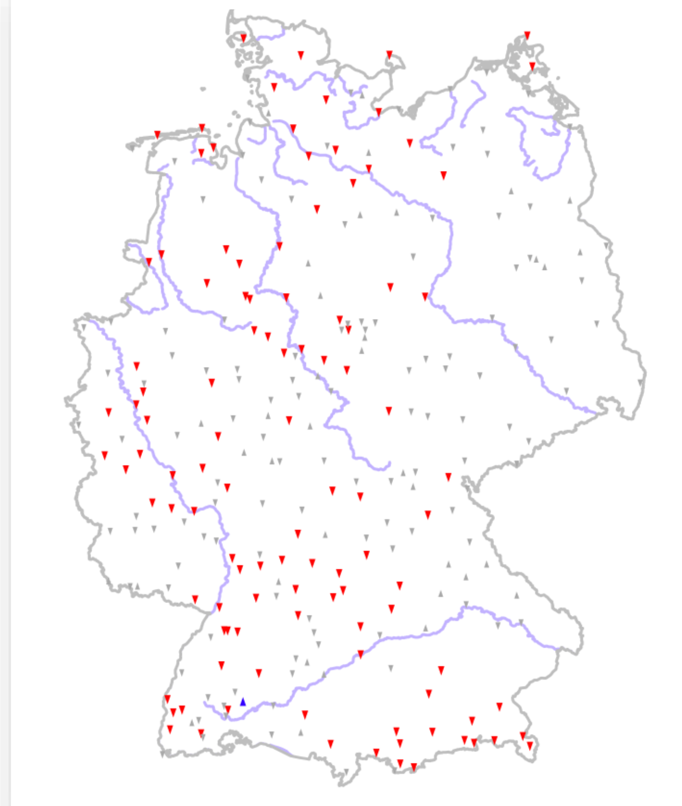
P. Hoffmann, PIK

Introduction Development of air humidity 1951-2006

Absolute Humidity

Relative Humidity



▲ Pos. trend p<0.10 | ▲ Pos. trend p>=0.10 | ▼ Neg. trend p>=0.10 | ▼ Neg. trend p<0.10

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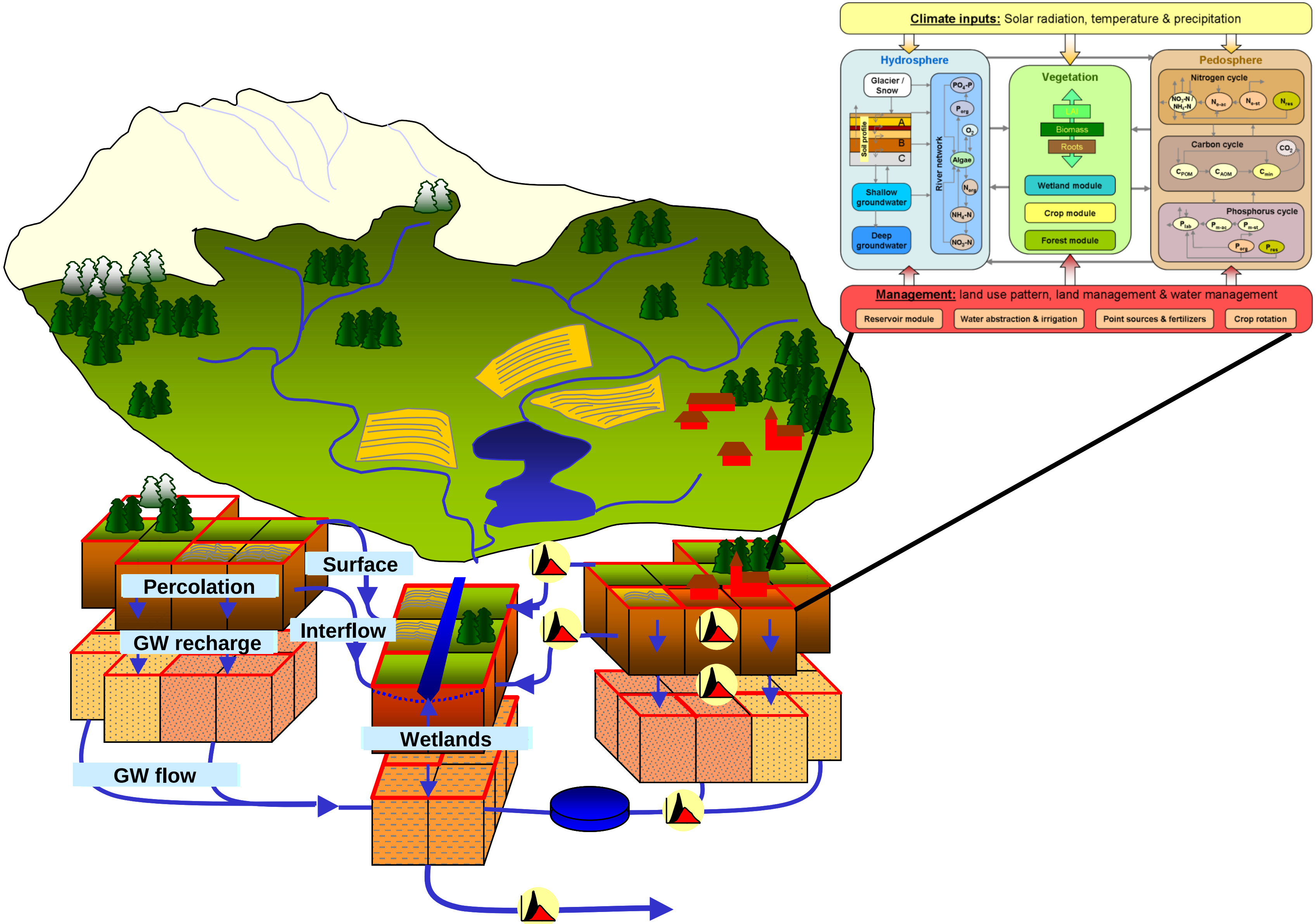
Data: DWD, Modelling: PIK
Hattermann et al. 2012a&b



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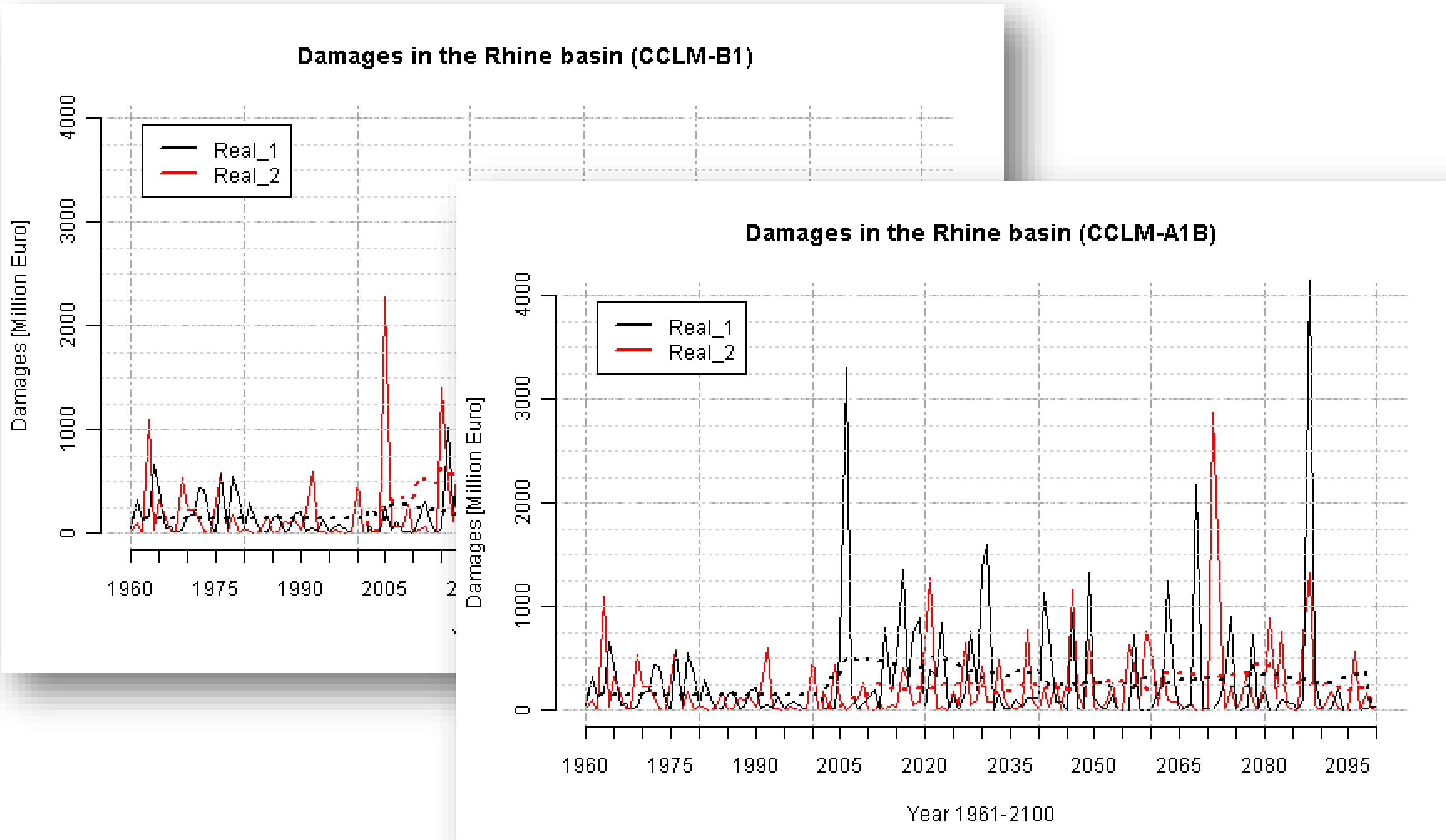
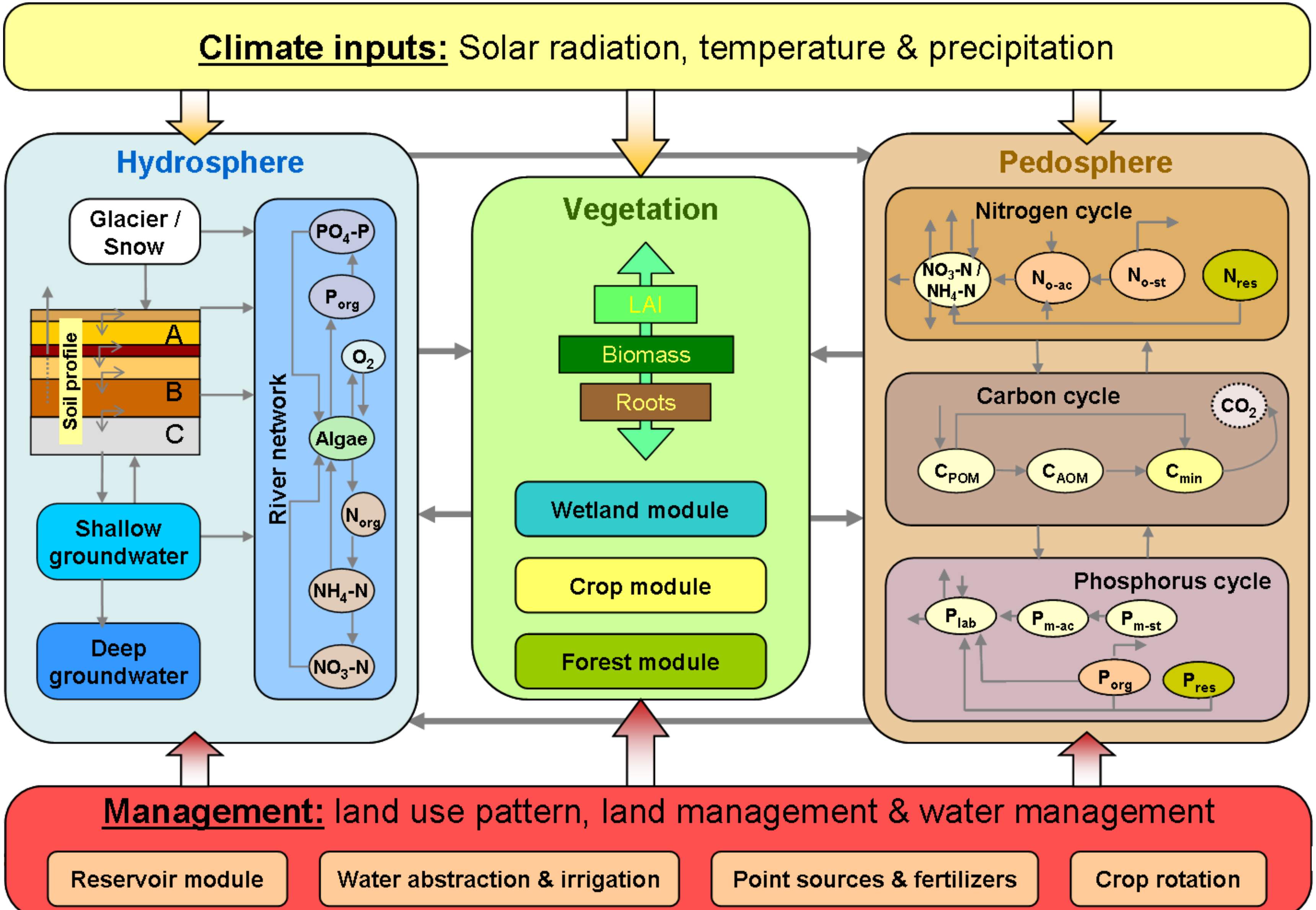
Results: Flood damages in the Rhine basin under climate change



Source of damage functions: German Insurance Association (GDV), modelled at PIK, Hattermann et al. 2014

PIK
Fred F. Hattermann

SWIM (Soil and Water Integrated Model) <-> SWAT



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