POTSDAM INSTITUTE FOR
CLIMATE IMPACT RESEARCH

PIK

Intercomparison of climate change impacts simulated by 9 hydrological models in 12 large river basins worldwide: a Synthesis

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*(**Regional Water Sector team in ISI-MIP**)*

Leibniz
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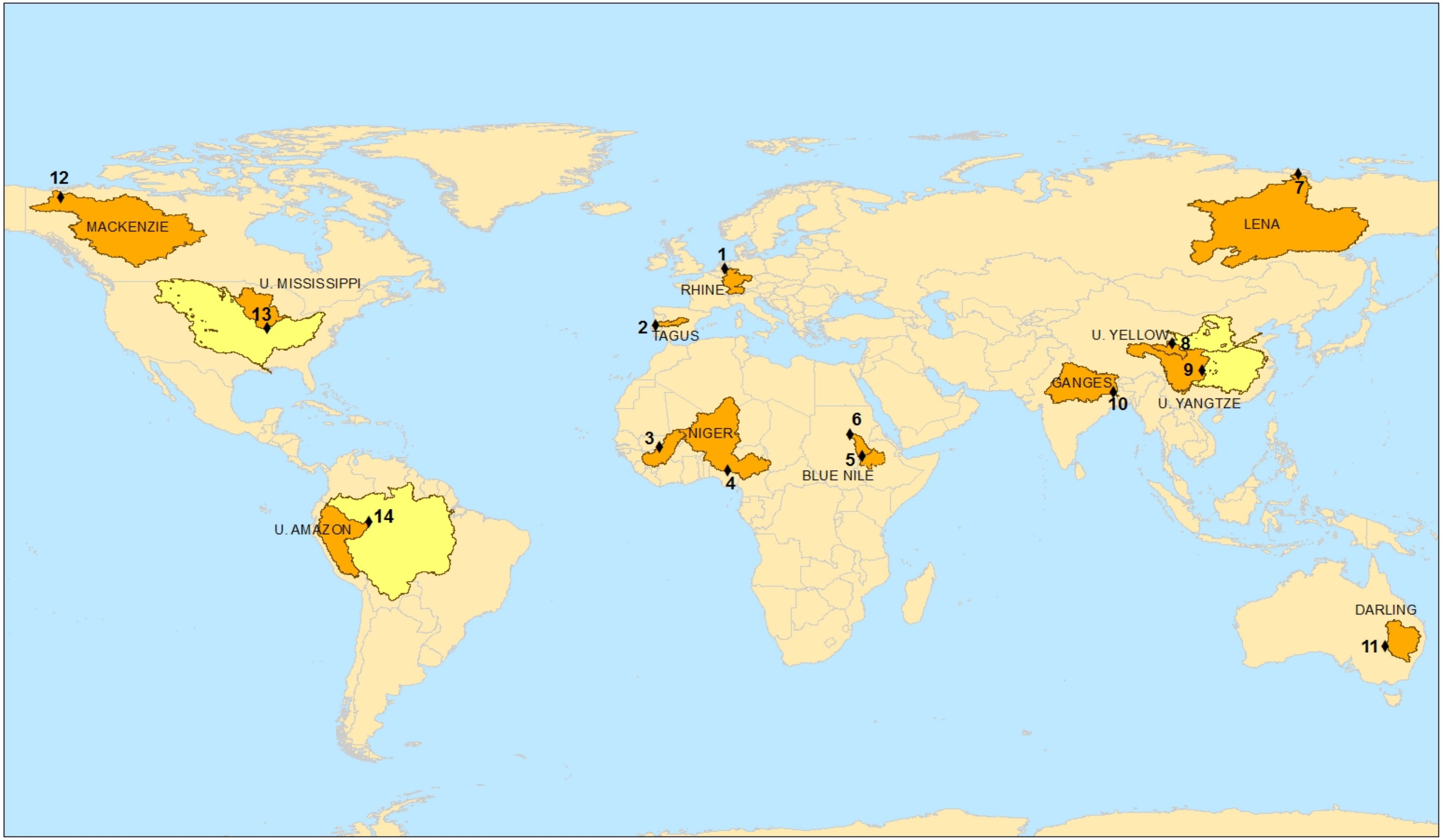
Potsdam Institute for Climate Impact Research
RD2 Climate Impacts
& Vulnerability

ISI-MIP project

- The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) is a community-driven modelling effort bringing together impact modellers across sectors and scales to create more consistent and comprehensive projections of climate change impacts.
- ISI-MIP is coordinated by PIK, Potsdam, with support from IIASA.
- Based on common scenarios, the impacts are derived from multiple impact models for different sectors, and uncertainties are evaluated.
- First results of ISI-MIP from the regional-scale models are published in Climatic Change Special Issue (April 2017).

12 river basins for regional-scale modelling



Europe
- ♦ 1. Lobith
- ♦ 2. Almourol

Africa
- ♦ 3. Koulikoro
- ♦ 4. Lokoja
- ♦ 5. El Deim
- ♦ 6. Khartoum

Asia
- ♦ 7. Stolb
- ♦ 8. Tangnaihai
- ♦ 9. Cuntan
- ♦ 10. Farakka

Australia
- ♦ 11. Louth

North America
- ♦ 12. Arctic Red River
- ♦ 13. Alton

South America
- ♦ 14. SP de Olivenca

Regional-Water team in ISI-MIP

Institution	*Country/ies*	*Coordinator(s)*	*Modeller(s)*	*Model(s)*
PIK	Germany	Krysanova, Hattermann	Vetter, Huang, Aich, Wortmann, Liersch, Reinhardt, Lobanova, Koch,	**SWIM, VIC, HBV**
many	Belgium, USA, Germany, Canada, Poland, Australia	van Griensven	Strauch, Tecklesadik, Daggupati, Seidou, Kundu, Piniewski, Vervoort, van Ogtrop	**SWAT**
CESR	Germany	Flörke	Eisner	**WaterGAP3**
SMHI	Sweden	Arheimer	Pechlivanidis, Donnelly, Hundecha,	**HYPE**
UFZ	Germany	Samaniego	Kumar	**mHM, HYMOD**
WPI	Russia	Gelfan	Motovilov, Krylenko, Kalugin	**ECOMAG**
HUni	China	Tao Yang	Wang, Shi	**VIC**
CNCC	China	Su Buda	Huang, Gao, Zeng	**SWAT, SWIM, HBV, VIC**
JLU	Germany	Breuer	Chamorro, Kraft	**HBV, HYMOD**
IIT	India	Mishra	Shah	**VIC**
IWW	Germany	Haberlandt	Plötner	**HBV**
WPI	Russia	Gusev	Nasonova	**SWAP**
IGSNRR	China	X. Mo	S. Liu	**VIP**

Climate scenarios

Climate scenarios from five CMIP5 Earth System Models:

- **HadGEM2-ES, Hadley Centre, UK;**
- **IPSL-CM5A-LR, The Institute Pierre Simon Laplace, France;**
- **MIROC-ESM-CHEM, University of Tokyo, Japan;**
- **GFDL-ESM2M, NOAA GFDL, USA;**
- **NorESM1-M, Norwegian Climate Centre, Norway**

are applied (after bias-correction) for 4 RCPs .

Simulations completed with 9 models

Basins	Rhine	Tagus	Niger		Blue Nile		Ganges	Yellow	Yangtze	Lena	Darling	MacKenzie	Mississippi	Amazon
Gauges	Lobith	Almourol	Lokoja	Koulikoro	Khartoum	El Deim	Farakka	Tangnaiha	Cuntan	Stolb	Louth	Ar. Red River	Alton	SP Olivenca
Models														
VIC	X	X	X	X	X	X	X	X	X	X	X		X	X
SWIM	X	X	X	X	X	X	X	X	X	X			X	X
WaterGAP3	X	X	X	X	X	X	X	X		X			X	X
mHM	X			X	X	X	X	X			X		X	X
HYMOD	X+X			X	X		X+X	X			X		X+X	X
HBV	X+X	X		X		X	X	X	X				X	X
SWAT				X		X			X		X		X	X
HYPE	X	X	X				X			X		X		
ECOMAG										X		X		
Applications	9	5	4	7	5	6	8	6	4	5	4	2	8	7

Climatic Change Special Issue, April 2017: 14 papers

Evaluation of models

- 12 stat. indices, return periods

Comparison of impacts

1-2 basins, multi-models

- MacKenzie, Lena
- Blue Nile
- Amazon
- Yangtze

5-12 basins, multi-models

- seas. dyn.
- extremes
- droughts
- IHA
- water balance

Sources of uncertainty

- HMs & parametrization

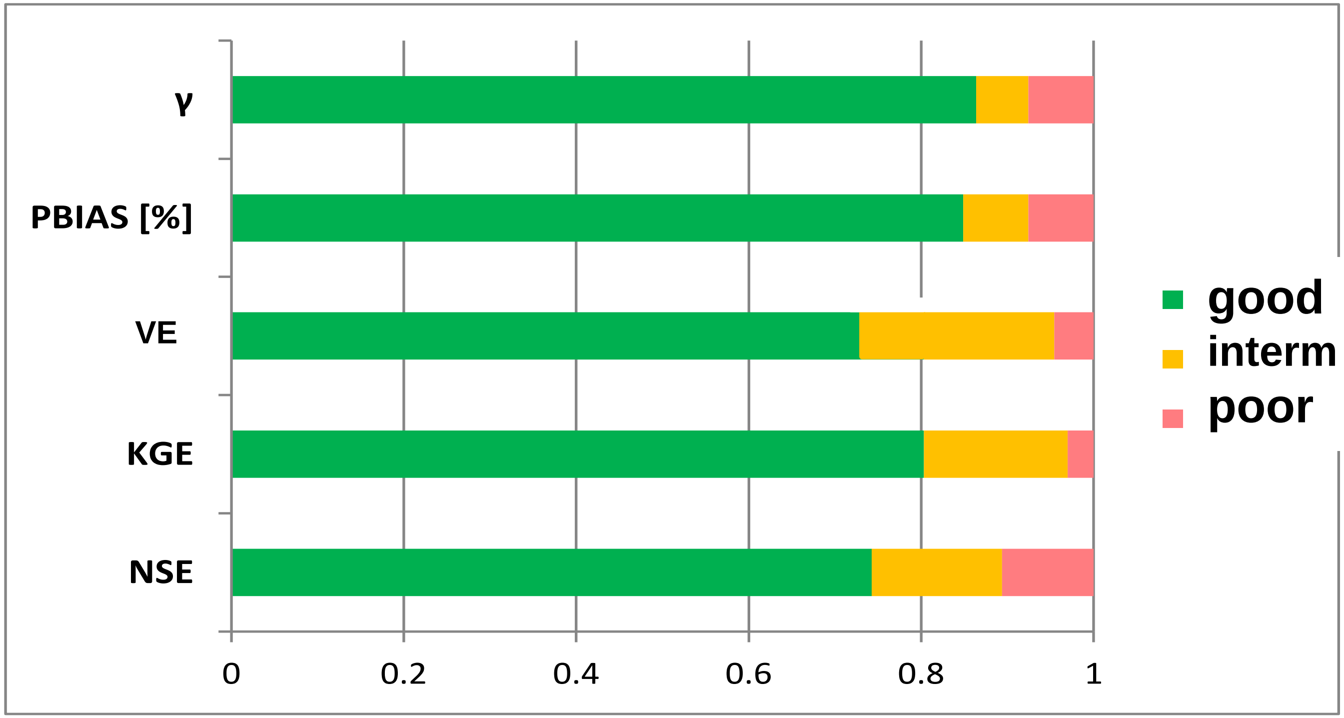
- seasonal dynamics
- ANOVA: 3 sources
- droughts

Global–Regional comparisons

- extremes: impacts

- validation & seasonal dynamics

Evaluation of models: monthly & seasonal dynamics (5 criteria)



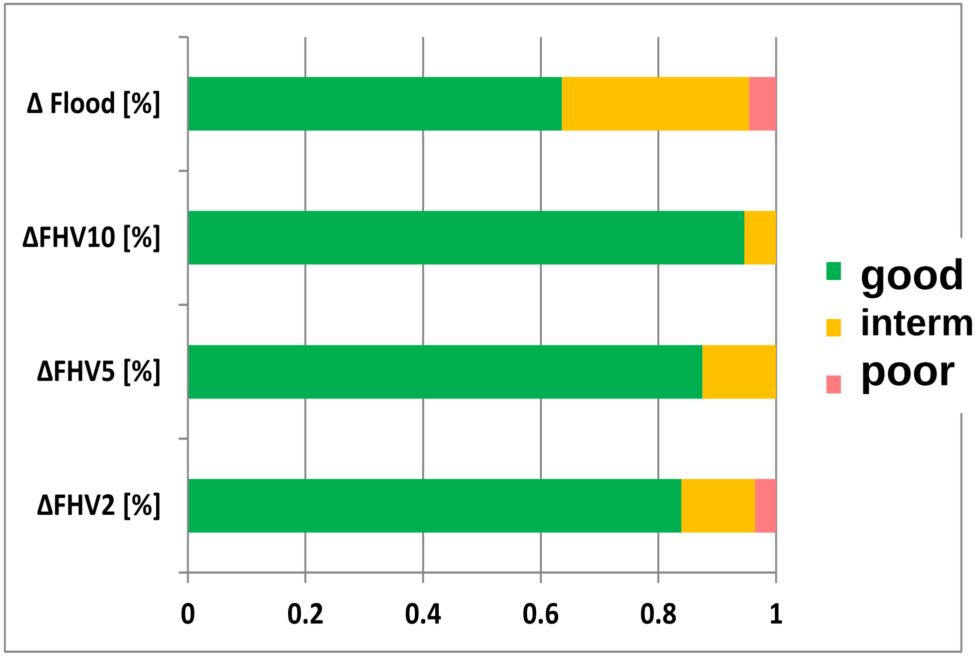
	NSE	KGE	PBIAS [%]	γ
🟩	> 0.7	> 0.7	+/- 15%	> 0.9
🟨				
🟥	< 0.5	< 0.5	> 30%	< 0.8

monthly

seasonal

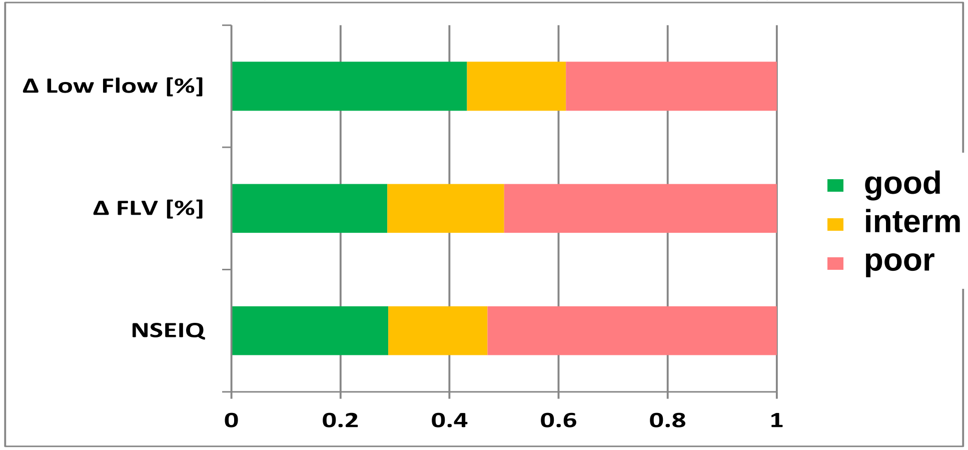
Huang et al., CC SI

Evaluation of models: floods and low flow (7 criteria)



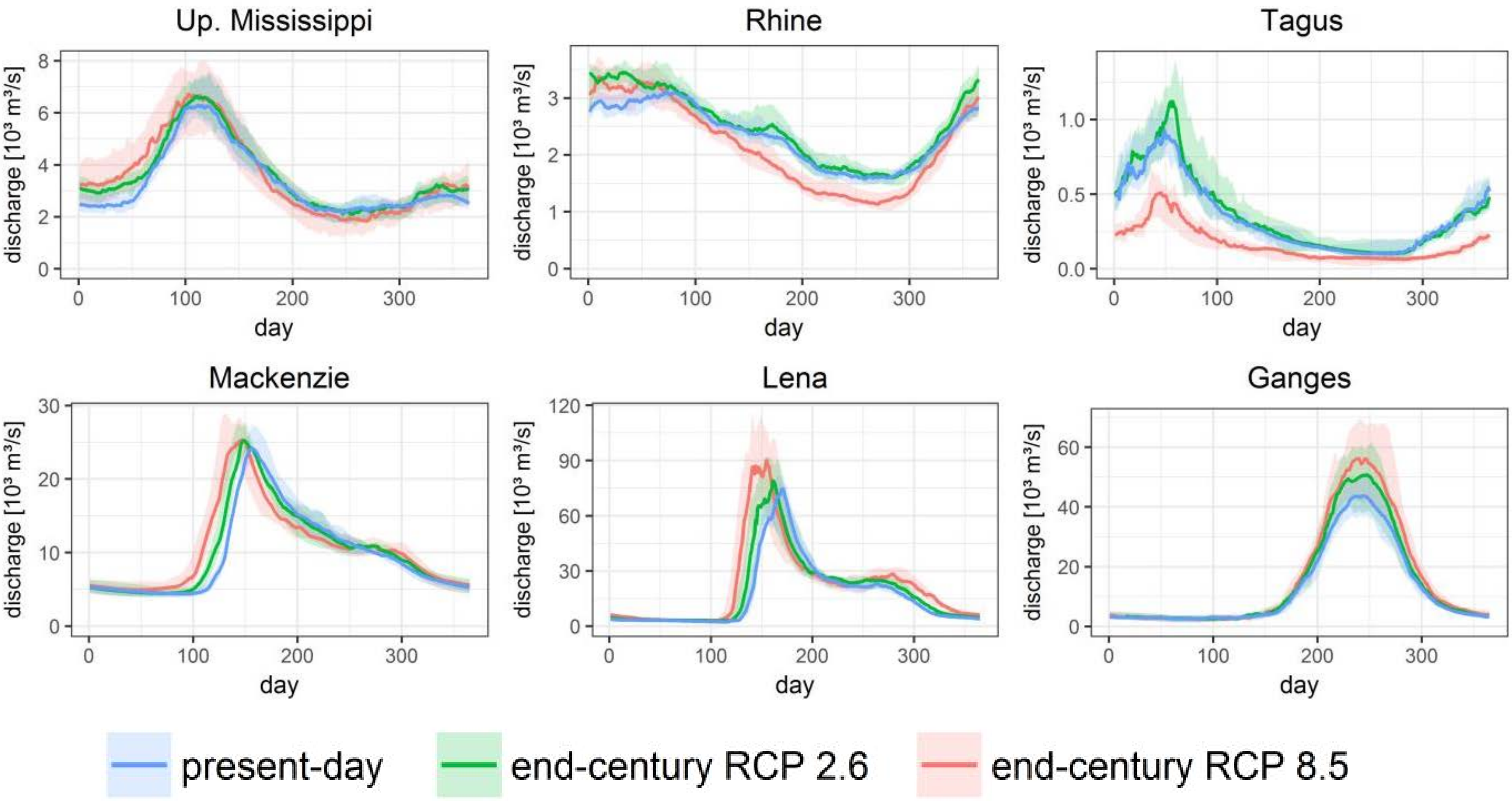
	ΔFHV2 [%]	ΔFHV5 [%]	FHV10 [%	Δ Flood [%]
🟩	+/- 25%	+/- 25%	+/- 25%	+/- 25%
🟨				
🟥	> 50%	> 50%	> 50%	> 50%

	NSEIQ	Δ FLV [%]	Δ Low Flow [%]
🟩	> 0.7	+/- 25%	+/- 25%
🟨			
🟥	< 0.5	> 50%	> 50%



More details: in Huang et al., CC SI

Impacts: seasonal dynamics



More details: in Eisner et al., CC SI

Impacts: high and moderate certainties (RCP8.5)

	Tagus			**Lena**			**Mackenzie**			**Yangtze**			**Ganges**			**Rhine**		
GCMs	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**
GFDL	-2	-2	-2	2	2	2	0	2	2	1	2	1	x	x	-1	1	-1	-1
HADGEM2	-2	-2	-2	2	2	2	1	2	2	2	2	2	2	2	x	1	-1	-2
IPSL	-2	-2	-2	2	2	2	-1	2	-1	0	1	-1	1	1	x	x	-1	-2
MIROC	-2	-2	-2	2	2	2	2	2	2	1	2	1	2	1	x	1	x	-1
NORESM	-2	-2	-2	1	2	2	1	2	2	1	1	x	1	1	1	1	-1	-1
	↓	↓	↓	↑	↑	↑		↑	↑	↑	↑		↑	↑		↑	↓	↓

	Niger			**Blue Nile**			**Darling**			**Amazon**			**Mississippi**			**Yellow**		
GCMs	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**	**HF**	**MF**	**LF**
GFDL	1	2	x	1	0	1	-1	-1	-2	0	0	0	1	0	0	x	x	x
HADGEM2	-1	-1	-2	x	x	x	1	2	-2	1	x	x	1	1	x	x	x	x
IPSL	-1	-2	-2	2	2	2	0	0	-1	-1	-1	1	-1	-1	-1	1	1	x
MIROC	2	2	1	-1	-1	-1	x	2	x	2	2	1	1	1	x	1	1	2
NORESM	-1	-2	-1	1	1	1	1	1	1	2	2	2	1	x	x	x	x	x

(high GCM uncertainty)

no trend

high HM uncert.

2	All HMs: stat. sign. positive trends
1	≥ 1 HM sign. positive trend, at least 1 insign. trend
0	No stat. sign. trends
-1	≥ 1 HM sign. negative trend, at least 1 insign. trend
-2	All HMs: stat. sign. negative trends
x	Disagreement: stat. sign. opposite trends

More details: in Vetter et al., CC SI

Summary on trends in mean flow, extremes (Q_{10} and Q_{90}) & 3-months high and low flows

River basin	Statistically significant trends Trend in Q10	 Trend in Q50	 Trend in Q90	Changes in high and low flows HF period, 3 mon.	 LF period, 3 mon.
Lena	⇑	⇑	⇑	**↑**	**↑**
MacKenzie	▨	⇑	⇑	↑	**↑**
Ganges	⇑	⇑	▨	**↑**	↓
Amazon	▨	▨	▨	**↑**	↑
Yangtze	▨	▨	▨	↑	↑
Yellow	▨	▨	▨	↑	↑
Mississippi	⇑	÷÷÷	÷÷÷	↑	**↓**
Rhine	⇑	⇓	⇓	↑	**↓**
Tagus	⇓	⇓	⇓	**↓**	**↓**
Darling	▨	▨	▨	≈≈	↓
Niger	▨	▨	▨	≈≈	↑
Blue Nile	▨	▨	▨	≈≈	≈≈

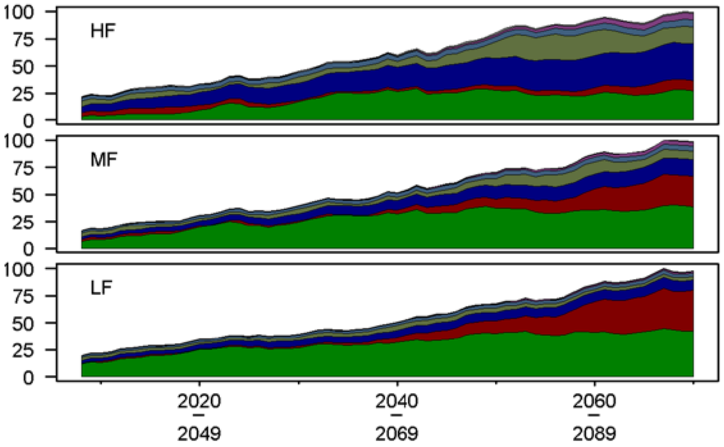
⇑	positive trend
⇓	negative trend
▨	trends contradict
÷÷÷	no sign. trend

↑	>75% increase by ≥ 5%
↓	>75% decrease by ≥ 5%
↑	>65% positive change
↓	>65% negative change
≈≈	insign. change

More details in Krysanova et al., ERL

Sources of uncertainty: four examples

Rhine

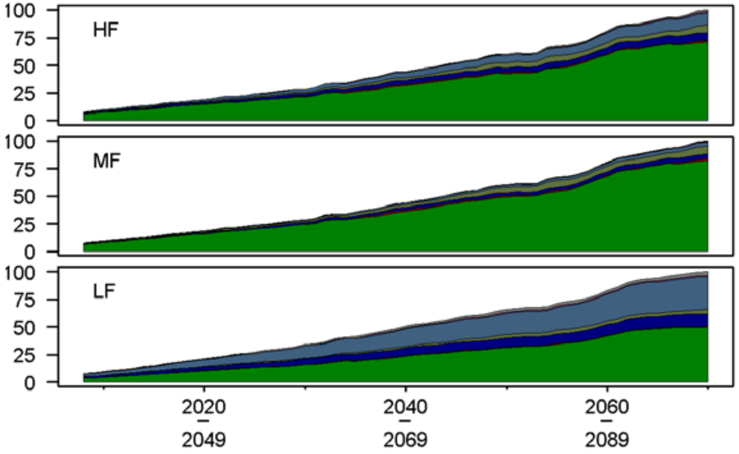


GCM+HM

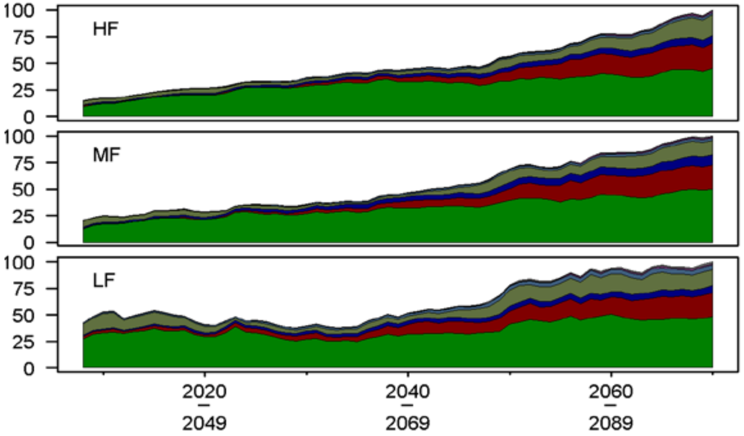
GCM+RCP

GCM+RCP

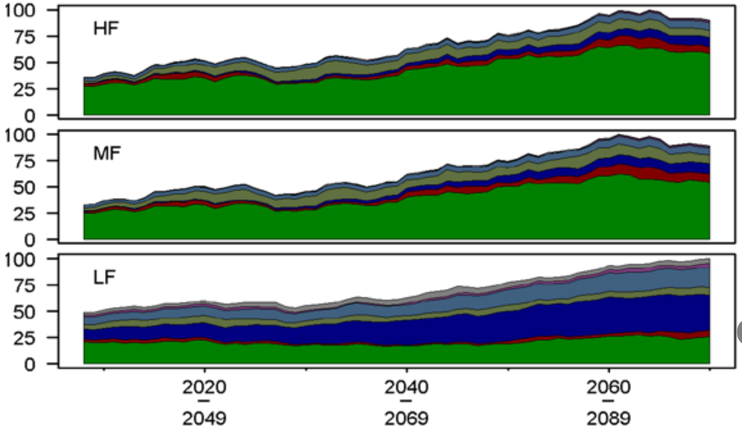
Niger: GCM prevails



Amazon: GCM & RCP



Ganges



GCM

GCM

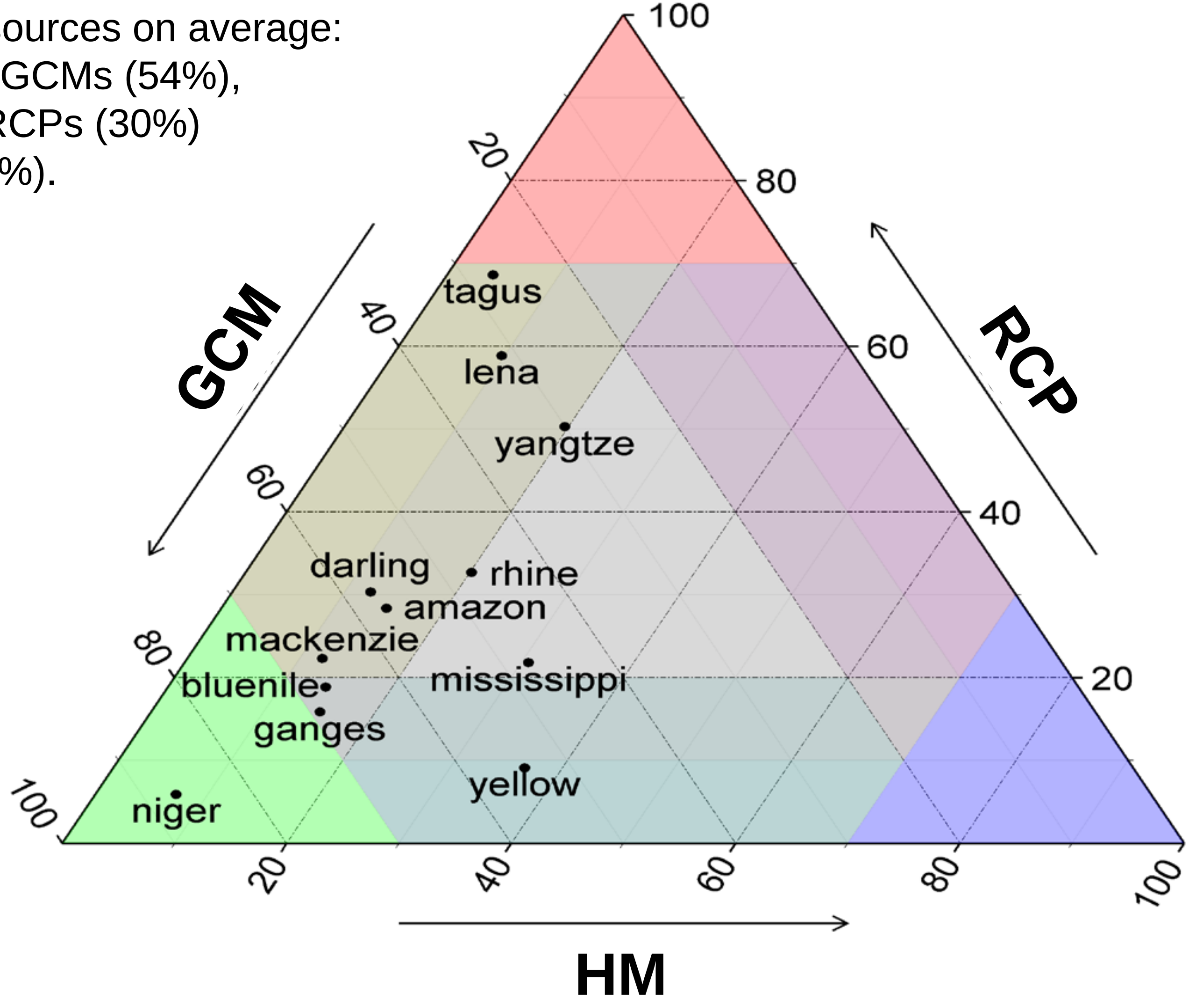
GCM+HM

🟩 GCM 🟥 RCP 🟦 HM

Vetter et al., CC SI

Triangle of uncertainty: where are the basins placed?

Uncertainty sources on average:
highest from GCMs (54%),
followed by RCPs (30%)
and HMs (16%).



Median Flow

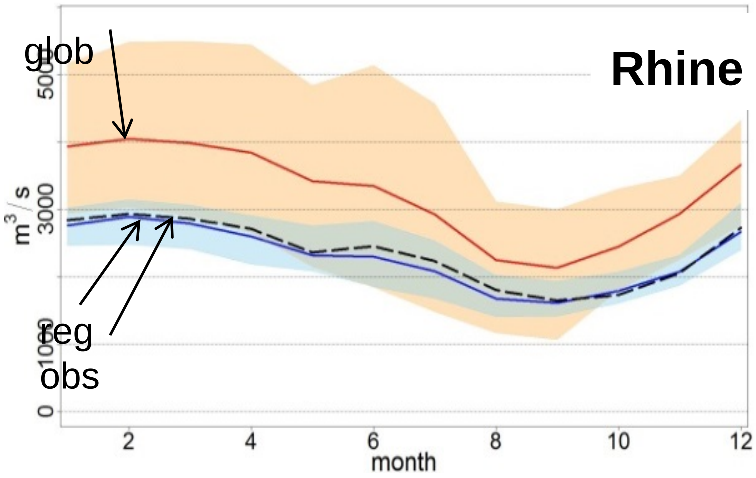
Vetter et al., CC SI

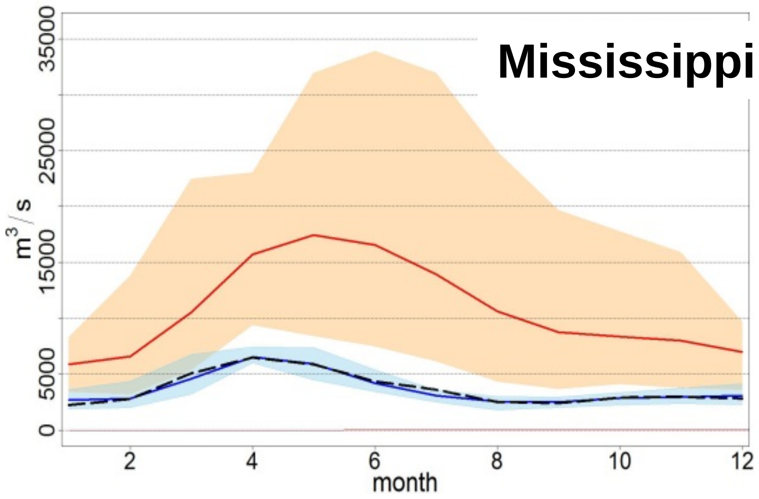
Summary on evaluation of uncertainty related to trends in mean flow and extremes (Q_{10} and Q_{90})

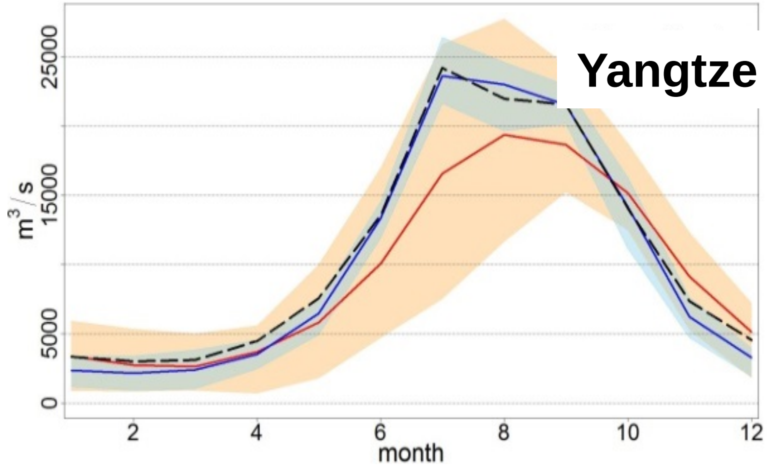
River basin	**Uncertainty sources**								
	Q10			Q50			Q90		
	GCM	RCP	HM	GCM	RCP	HM	GCM	RCP	HM
Lena	X	XXX		X	XXXX			X	XXX
MacKenzie	XXX		XX	XXXXX			XXX		XX
Ganges	XXXXX			XXXXX			XX		XX
Amazon	XXX	X		XXXX	X		XXXX	X	
Yangtze	XXX		X	XXX		X	XXX		X
Yellow	XXX		XX	XXX		XX	XXX		XX
Mississippi	XXX	X		XXX		X	X		XXX
Rhine	XX		XX	XXX	X		XXX	XX	
Tagus	X	XXXXX		X	XXXXX			XXXX	
Darling	XXX	XX		XXXX	X		XXXX		
Niger	XXXXX			XXXXX			XXXXX		
Blue Nile	XXXXX			XXXXX			XXX	X	

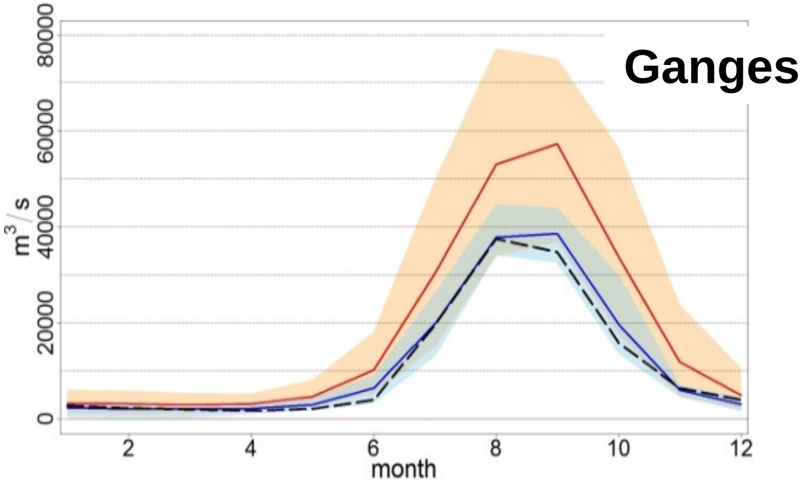
XXXXX	>65%
XXXX	>55%
XXX	>45%
XX	>35%
X	>25%
	<25%

Cross-scale comparisons using global and regional hydrological models









More information: in Fred Hattermann' talk 29.06

Conclusions

- **Performance** of regional models for monthly/seasonal flow & high flow is good, but it is poor for low flow.
- **Performance** of regional models for seasonal dynamics is much better than that of global models (which are usually not calibrated).
- **Impacts with a high/moderate certainty found** for: Lena, Tagus, MacKenzie, Rhine, Ganges, Mississippi;
- **Impact not found** for: Niger, Blue Nile and Darling
- **Uncertainty sources**: the highest from GCMs (54% for MF), followed by RCPs (30%: scenario uncertainty!) and HMs (16%).

⇨

- **GCMs improvement needed**: in Africa and Australia.
- **HMs improvement needed**: in snow-dominated basins & for low flow

Thanks for your attention!

You are welcome to join our Regional-Water team in ISI-MIP!

a) to run new climate scenarios from the 17th century with/without dynamic land cover,

and

a) to further increase visibility and popularity of SWAT, (still needed?)

Criterion	Full name	Formula	Reference
NSE	Nash-Sutcliffe Efficiency calculated on flows	$1-\frac{\sum_{t=1}^{N}(Q_{s,t}-Q_{o,t})^2}{\sum_{t=1}^{N}(Q_{o,t}-\overline{Q_o})^2}$	(Nash and Sutcliffe, 1970)
NSEiq	NSE calculated on inverse transformed flows	$1-\frac{\sum_{t=1}^{N}(\frac{1}{Q_{s,t}+\varepsilon}-\frac{1}{Q_{o,t}+\varepsilon})^2}{\sum_{t=1}^{N}(\frac{1}{Q_{o,t}+\varepsilon}-\overline{\frac{1}{Q_{o,t}+\varepsilon}})^2}$	(Pushpalatha et al., 2012)
KGE	Modified Kling-Gupta efficiency	$1-\sqrt{(r-1)^2+(\beta-1)^2+(\gamma-1)^2}$	(Kling et al.,2012)
VE	Volumetric efficiency	$1-\frac{\sum_{t=1}^{N}\lvert Q_{s,t}-Q_{o,t}\rvert}{\sum_{t=1}^{N}Q_{o,t}}$	(Criss and Winston, 2008)
PBIAS	Percent bias in overall flows	$\frac{\sum_{t=1}^{N}(Q_{s,t}-Q_{o,t})}{\sum_{t=1}^{N}Q_{o,t}}*100$	(Moriasi et al., 2007)
r	Pearson's correlation coefficient	$\frac{\sum_{t=1}^{12}(Q_{s,t,}-\bar{Q}_s)(Q_{o,t}-\bar{Q}_o)}{\sqrt{\sum_{t=1}^{12}(Q_{s,t}-\bar{Q}_s)^2}\sqrt{\sum_{t=1}^{12}(Q_{o,t}-\bar{Q}_o)^2}}$	(Gudmundsson et al., 2012b)
ΔFMS	Percent bias in flow duration curve (FDC) midsegment slope	$\frac{[\log(Q_{s,m1})-\log(Q_{s,m2})]-[\log(Q_{o,m1})-\log(Q_{o,m2})]}{\log(Q_{o,m1})-\log(Q_{o,m2})}*100$	(Yilmaz et al., 2008)
ΔFHV	Percent bias in FDC high-segment volume	$\frac{\sum_{h=1}^{H}(Q_{s,h}-Q_{o,h})}{\sum_{h=1}^{H}Q_{o,h}}*100$	(Yilmaz et al., 2008)
ΔFLV	Percent bias in FDC low-segment volume	$-1*\frac{\sum_{l=1}^{L}[\log(Q_{s,l})-\log(Q_{s,L})]-\sum_{l=1}^{L}[\log(Q_{o,l})-\log(Q_{o,L})]}{\sum_{l=1}^{L}[\log(Q_{o,l})-\log(Q_{o,L})]}*100$	(Yilmaz et al., 2008)
ΔFlood	Percent bias in the 10 and 30-year flood levels	$\frac{(FQ10_s+FQ30_s)-(FQ10_o+FQ30_o)}{(FQ10_o+FQ30_o)}*100$	
Δ LF	Percent bias in the 10 and 30-year low flow levels	$\frac{(LQ10_s+LQ30_s)-(LQ10_o+LQ30_o)}{(LQ10_o+LQ30_o)}*100$	

ε: a small constant

r: correlation coefficient between simulated and observed runoff

β: bias ration

γ: the variablity ration

m1 and m2: the 0.2 and 0.7 flow exceedance probabilites.

h: the flow indices for flow exceedance probabilities lower than 0.05.

H: the index of flow exceedance probability of 0.05

l: the index of flow value within the low-flow segment (0.7-1.0 flow exceedance probabilites) of the flow duration curve.

L: the index of the minimum flow.

How to do CC impact assessment: advices for non-experienced users

- **Compare projections in future periods only to the model outputs in the historical period driven by climate from the same source, never to the observed discharge, or simulated discharge driven by observed climate;**

- **Always use 30 yr periods for analysis of projections, not shorter!**

- **Bias-correction of climate scenarios is not a must, applying climate scenarios without bias correction is also possible.**