Climate change impact on streamflow in ISI-MIP large-scale river basins: projections and their uncertainties

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2017

Objective

Application of the LSM SWAP to assess climate change impact on streamflow of large rivers selected within the framework of ISI-MIP using meteorological projections from five GCMs up to 2100.

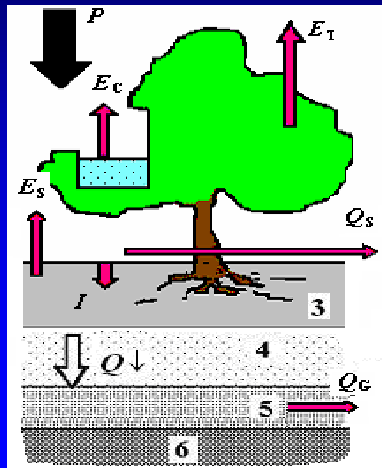
Goals:

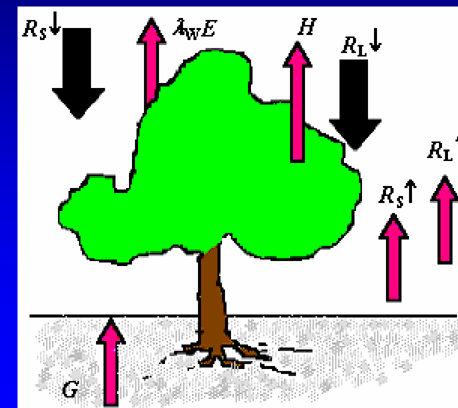
1. **To obtain optimal values of model parameters for 12 ISI-MIP river basins using the land surface model SWAP and meteorological data from the WATCH data set.**
2. **To perform historical simulations of river runoff using LSM SWAP with optimal parameters and meteorological forcing data simulated by 5 GCMs and compare the results of simulated runoff with measurements.**
3. **To obtain river runoff projections up to 2100 using meteorological projections simulated by 5 GCMs for 4 climatic scenarios of the RCP family (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) .**
4. **To estimate the uncertainties in runoff projections resulted from application of different GCMs and different climatic scenarios.**

Land surface model SWAP

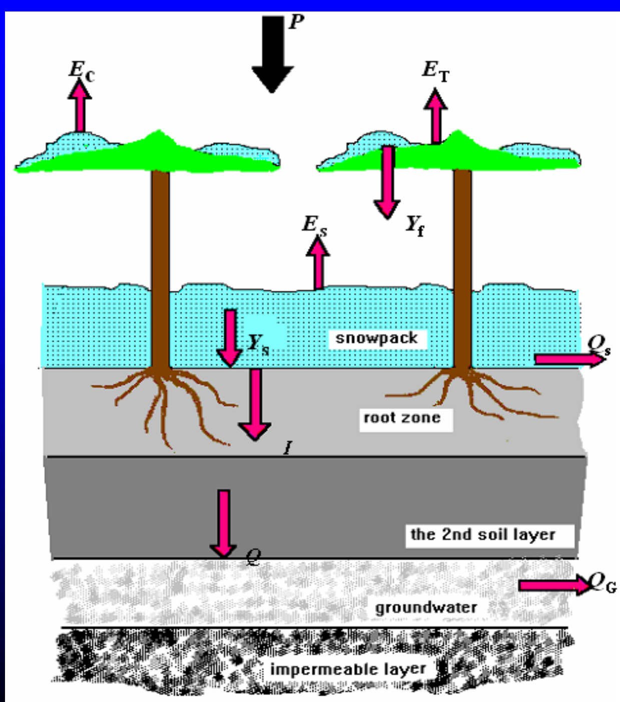
Water balance components

Heat balance components

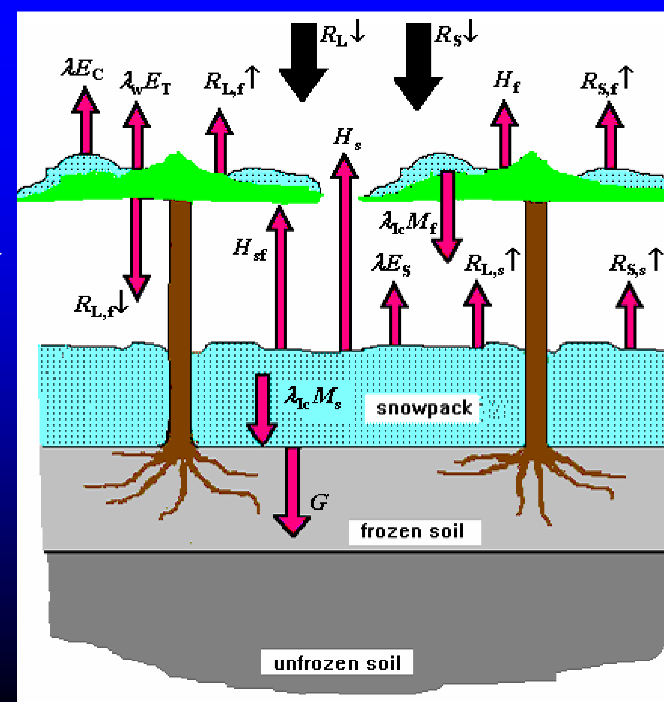




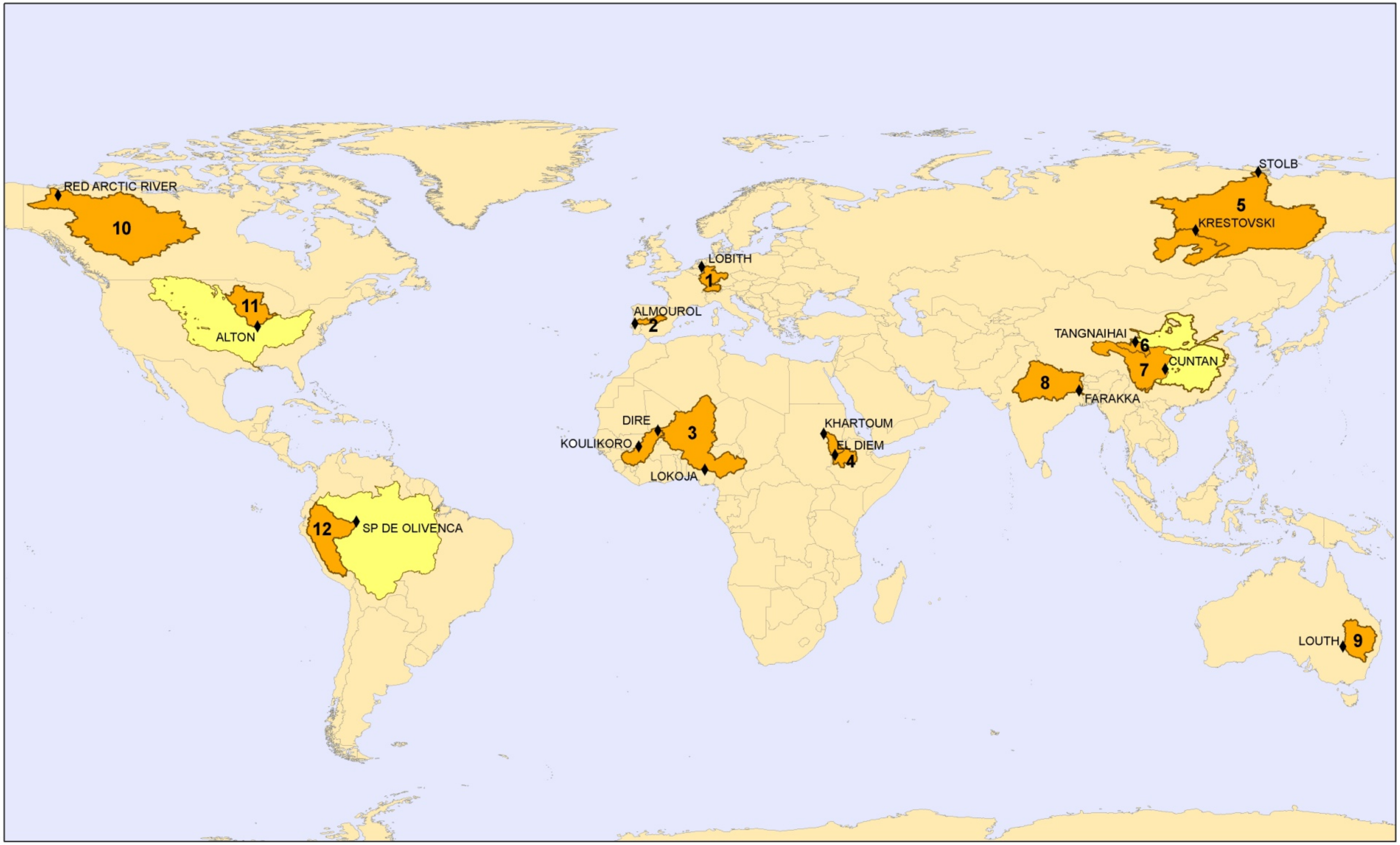
← Warm season →



← Cold season →



ISI-MIP river basins



Europe
- 1. Rhine
- 2. Tagus

Africa
- 3. Niger
- 4. Blue Nile

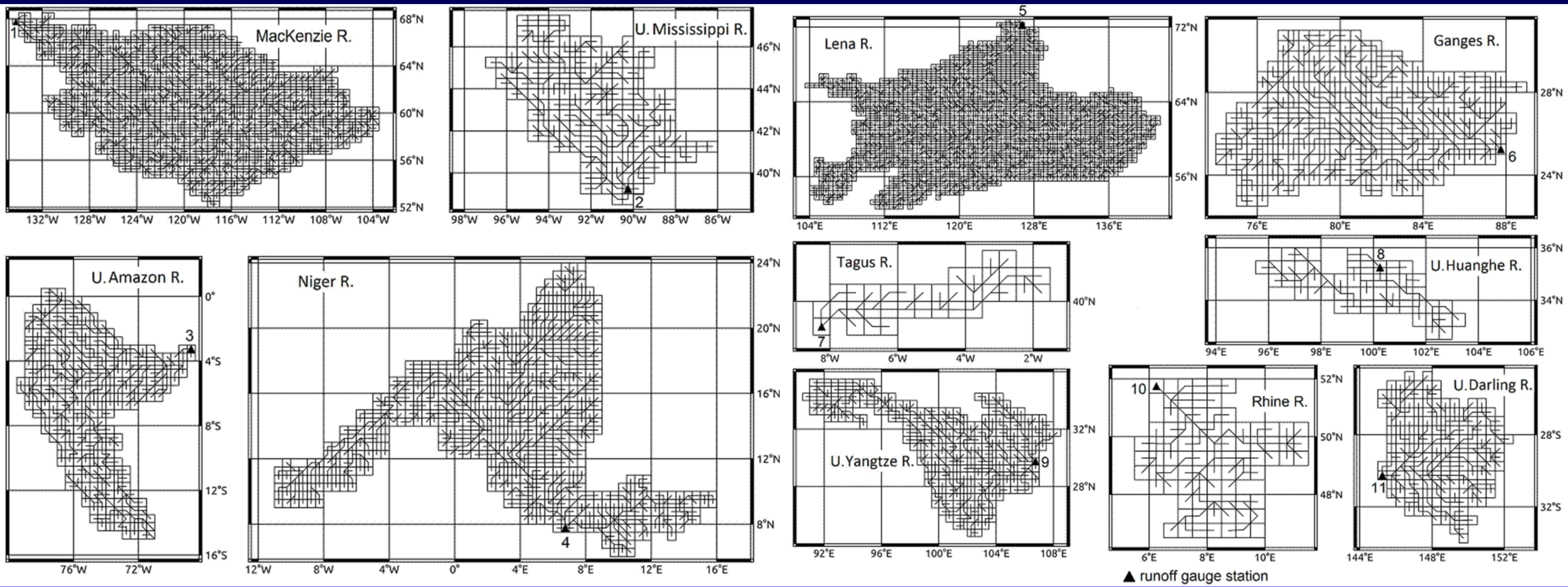
Asia
- 5. Lena
- 6. Upper Yellow
- 7. Upper Yangtze
- 8. Ganges

Australia
- 9. Darling

North America
- 10. Mackenzie
- 11. Upper Mississippi

South America
- 12. Upper Amazon

Schematization of the river basins



The basins were presented as a set of regular grid cells (with a spatial resolution 0.5°×0.5° in latitude and longitude) connected by a river network.

River	Area(km^2)	Number of grid cells	T,°C	P, mm/year	R, mm/year	R/P
Lena	2 460 000	1668	-10.2	384	201	0.52
MacKenzie	1 660 000	1128	-4.3	435	171	0.39
Niger	2 074 171	678	27.7	625	77	0.12
Ganges	835 000	340	21.1	1173	471	0.40
U. Amazon	990 781	330	21.7	2122	1459	0.69
U. Yangtze	804 859	325	6.8	768	389	0.51
U. Mississippi	444 185	198	7.3	967	257	0.27
Darling	489 300	180	19.2	590	8	0.01
Rhine	160 800	83	8.7	1038	457	0.44
U. Huanghe (Yellow)	121 000	51	-2	506	169	0.33
Tagus	67 490	35	14	671	152	0.23

Calibration of model parameters

Vegetation and soil parameters were taken or derived from the ECOCLIMAP database

Calibrated parameters for all basins

Adjustment factors for
- soil hydraulic conductivity at saturation K_0 ;
- root layer depth h_r .

Coefficient k_{h0} for soil column depth in $h_0 = k_{h0}\, h_r$.

Manning coefficient n.
Effective velocity of water movement in a channel network u_e.

Adjustment factors for longwave and shortwave radiation k_{sw} and k_{lw} , respectively.

Rain-dominated basins

\+
Leaf area index LAI.

Snow-dominated basins

\+
Adjustment factor for snow free albedo of the land surface alb_{sum}.
Albedo of fresh snow alb_{sn}.

Calibration technique

SCE-UA - Shuffled Complex Evolution method

Objective function:

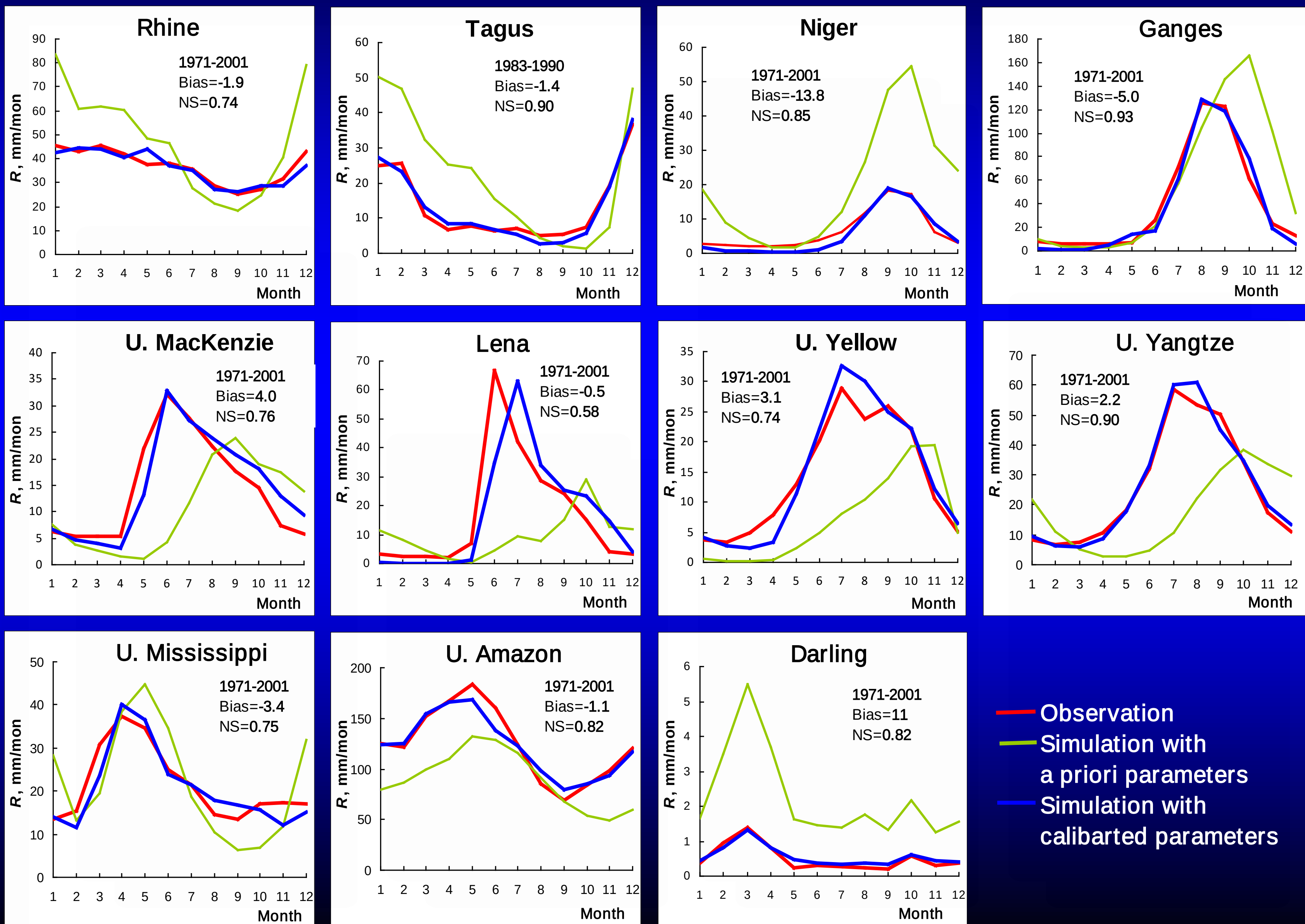
$$NS = 1 - \frac{\sum_{\Omega} (x_{sim} - x_{obs})^2}{\sum_{\Omega} (x_{obs} - \overline{x}_{obs})^2}$$

Condition: $|Bias| \leq 5\%$

$$Bias = \frac{\sum_{\Omega} (x_{sim} - x_{obs})}{\sum_{\Omega} x_{obs}} 100\%$$

For model calibration, meteorological forcing data with one-day temporal resolution for each calculational grid cell of the river basins were taken from the global WATCH data set.

Validation of monthly hydrographs simulated by SWAP



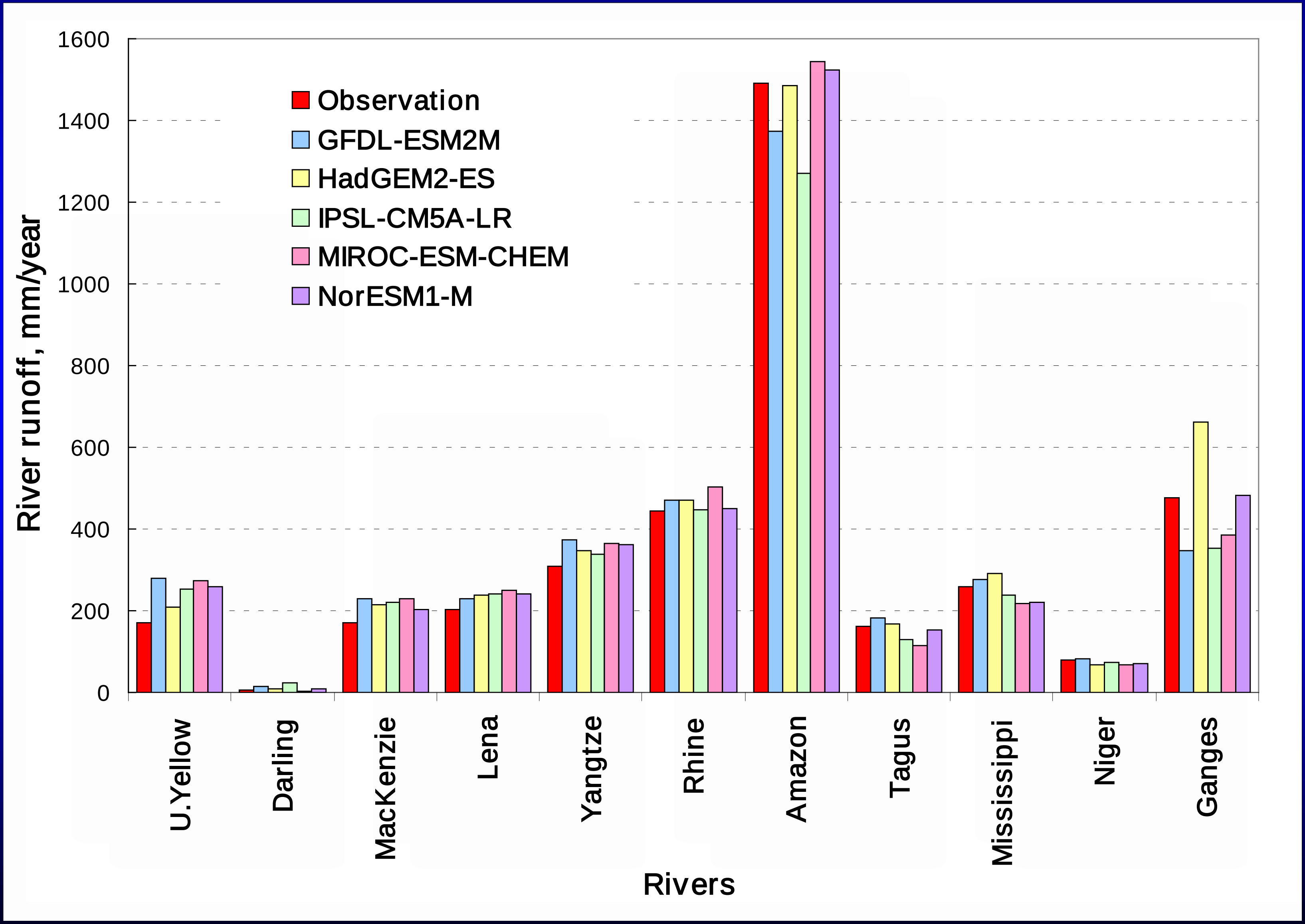
Forcing data from five GCMs:
historical simulations (1971-2005) and projections (2006-2099)

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

Climate scenarios for 4 RCPs (Representative Concentration Pathways) : RCP2.6, RCP4.5, RCP6.0, RCP8.5

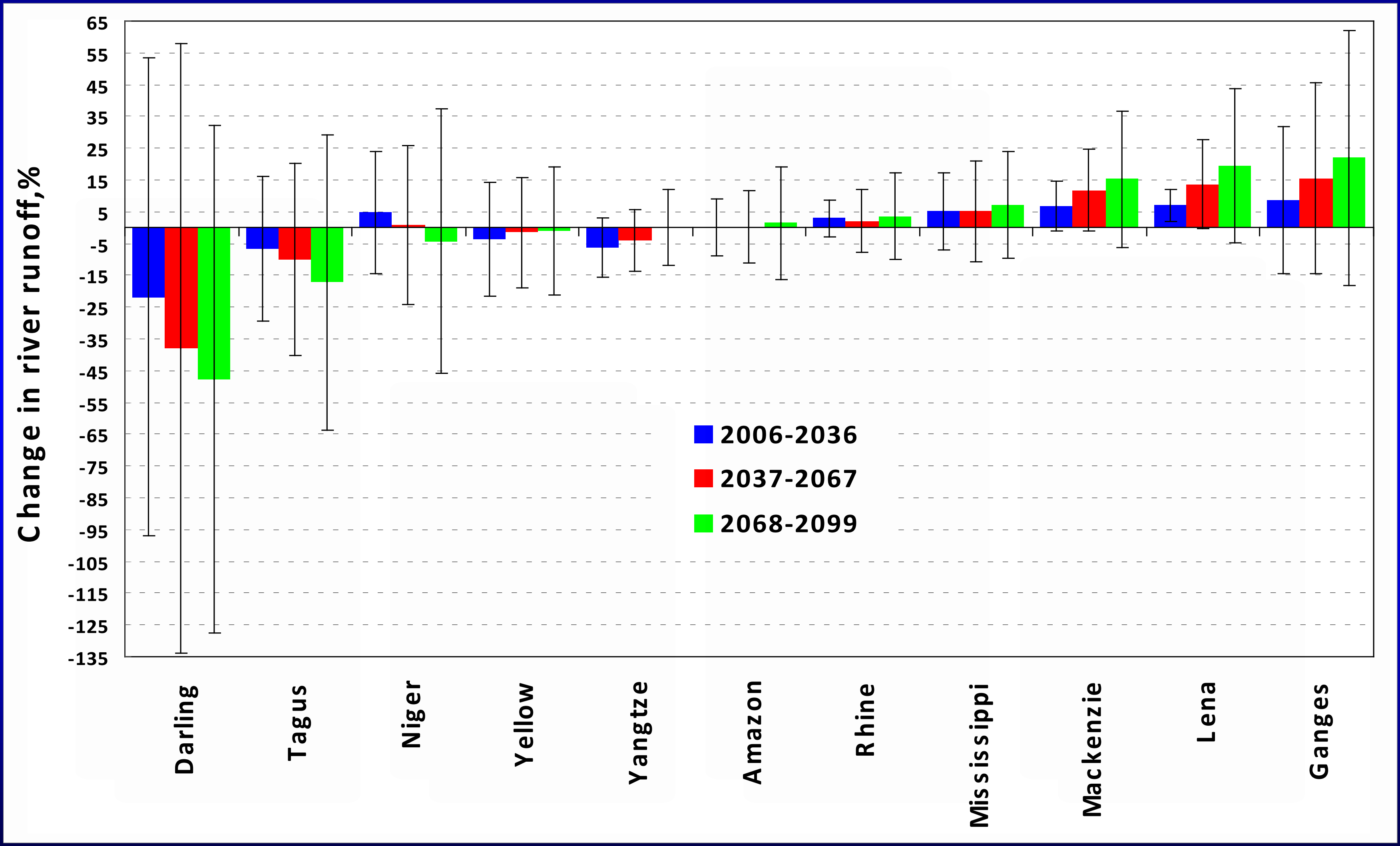
Forcing data were bias-corrected to WATCH.

Validation of historical simulations of annual river runoff by the SWAP model driven by forcing data from five GCMs



The projected mean relative changes in annual river runoff and their uncertainties

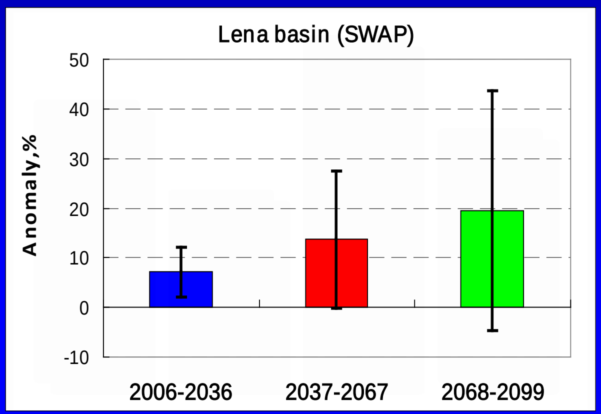
(caused by application of different GCMs and RCP scenarios)



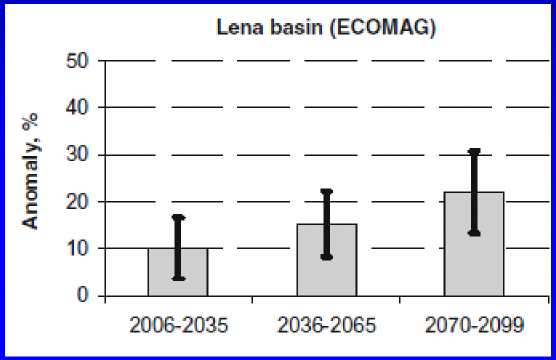
Bars are the intervals (MEAN±1.96 STD) treated as hydrological uncertainty caused by both the model structural uncertainty and the climate scenario variability.

Comparison of the mean relative changes in annual runoff of the Lena and Mackenzie rivers projected by the SWAP, ECOMAG and HYPE models

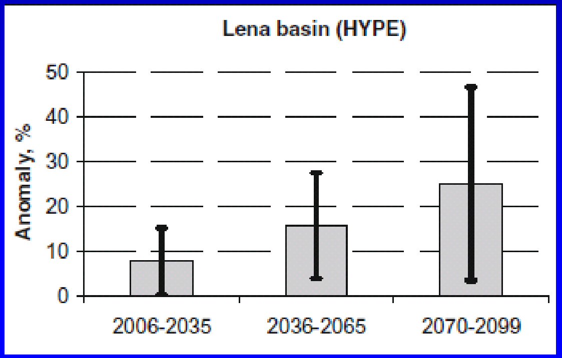
SWAP



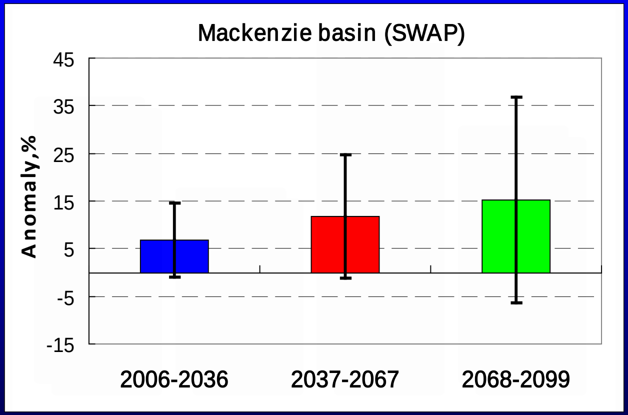
ECOMAG



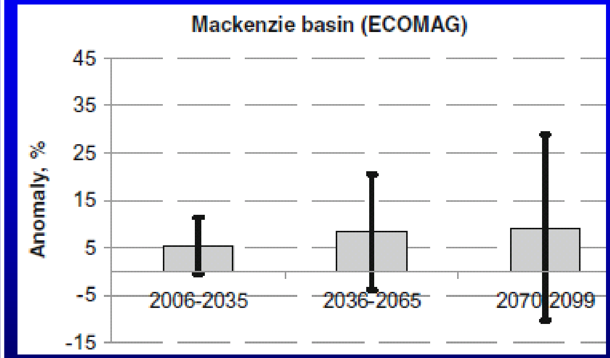
HYPE



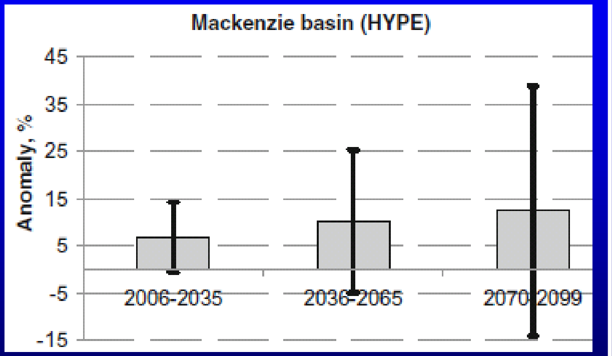
SWAP



ECOMAG

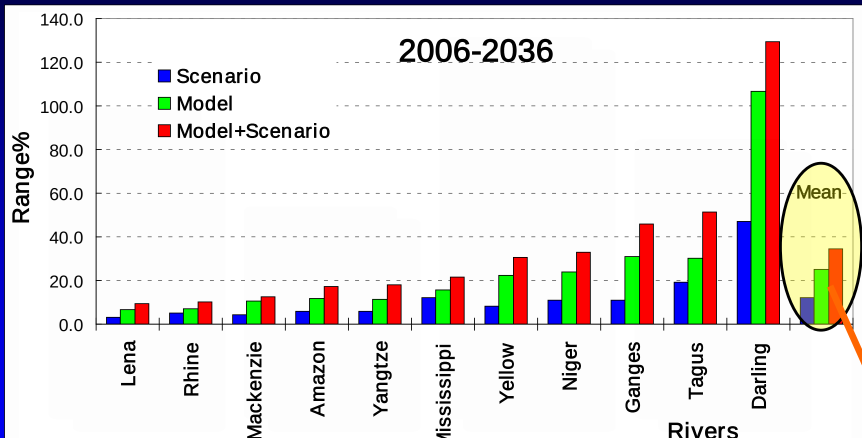


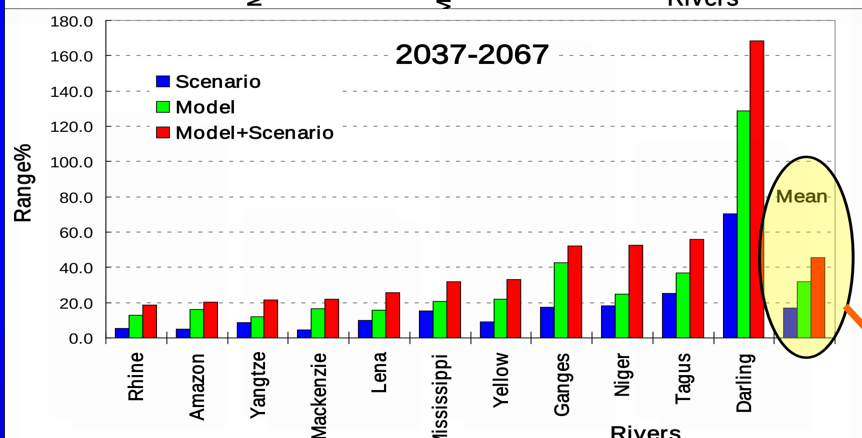
HYPE

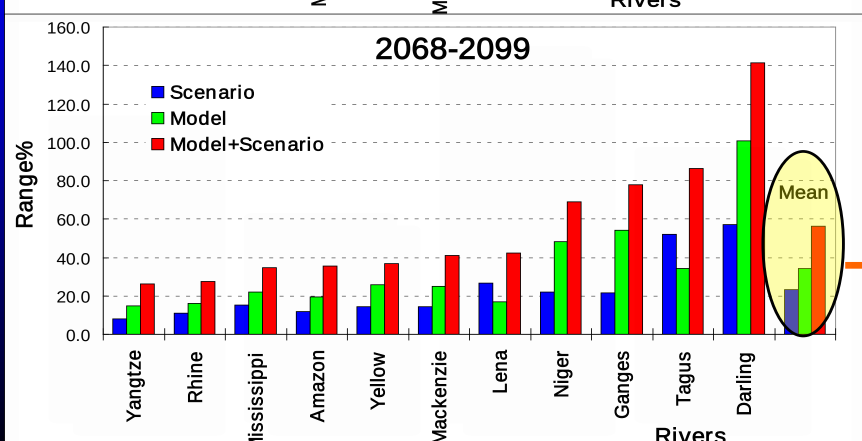


A. Gelfan, D. Gustafsson, Yu. Motovilov, B. Arheimer, A. Kalugin, I. Krylenko, A. Lavrenov. 2017. Climate change impact on water regime of great 1 Arctic rivers: modeling and uncertainty issues. Climatic Change.141:499-515.

Uncertainties in river runoff projections due to different GCMs and RCP scenaries







4 periods:

- ♦ **Historical (1971-2005)**
- ♦ **2006-2036**
- ♦ **2037-2067**
- ♦ **2037-2067**

5 GCMs

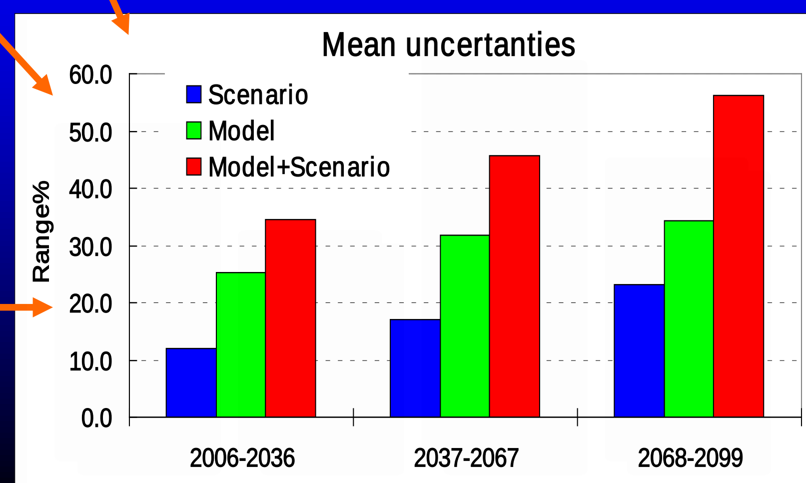
4 scenarios

$$\Delta R_{\text{model}} = R_{\text{model, projected}} - R_{\text{model, hist}}$$

$$\Delta R_{\text{model}}\% = \frac{\Delta R_{\text{model}}}{R_{\text{model, hist}}} \times 100\%$$

$$Range = \Delta R_{\max} - \Delta R_{\min}$$

$$Range\% = \Delta R\%_{\max} - \Delta R\%_{\min}$$



CONCLUSIONS

Calibration of the most influencing parameters against measured monthly river runoff resulted in significant improvement of SWAP performance with respect to goodness-of-fit statistics and the shape of hydrograph. For the calibration period, lBiasl did not exceed 5% for all rivers, NS varied from 0.68 to 0.95 (median value = 0.87). For the validation period lBiasl did not exceed 13.8%, NS varied from 0.58 to 0.90 (median value = 0.76).

Historical simulations of river runoff performed by SWAP with application of the obtained optimal parameters and meteorological forcing data simulated by 5 GCMs were validated against measured annual runoff and showed a good agreement.

River runoff projections up to the end of the 21st century were carried out with the help of SWAP driven by meteorological projections simulated by 5 GCMs for 4 climatic scenarios of the RCP family (RCP2.6, RCP4.5, RCP6.0 and RCP8.5). For some rivers (Amazon, Rhine, Mississippi, Mackenzie, Lena and Ganges), runoff will increase by the end of the 21st century by 1.4 - 22%, for the other three rivers (Niger, Tagus and Darling) runoff will decrease by 4 - 48%, while for the Yellow and Yangtze rivers there will be no changes in runoff.

Analysis of uncertainties of river runoff projections has shown that:

(1) the largest uncertainties resulted from application of different GCMs and different climatic scenarios were obtained for the Darling and Tagus rivers;

(2) the uncertainties increase by the end of the 21st century;

(3) on the average, the contribution of different GCMs in the uncertainty of river runoff is larger (nearly twice in 2006-2067 and 1.5 times in 2068-2099) than the contribution of different scenarios.

Thank you!