International Commission for the Hydrology of the Rhine Basin
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RheinBlick2050

Joint Climate and Discharge Projections for the Rhine Overview

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CRP-GL / EVA / GEOSAT
Belvaux, Luxembourg
http://www.lippmann.lu

Centre de Recherche Public Gabriel Lippmann

O. de Keizer

Deltares Enabling Delta Life

J. Beersma

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Verkeer en Waterstaat

H. Buiteveld
R. Lammersen

Rijkswaterstaat
Ministerie van Verkeer en Waterstaat

P. Krahe
M. Carambia
E. Nilson

bfg Bundesanstalt für Gewässerkunde

C. Perrin

Cemagref Sciences, eaux & territoires

G. Brahmer

HLUG

D. Volken

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Bundesamt für Umwelt BAFU

Deltas in Times of Climate Change, Rotterdam, 29 Sept - 1 Oct 2010; Scientific Programme / Deltas in Depth;
Theme 1: Regional climate, sea level rise, storm surges, river run-off and coastal flooding; Precipitation, discharge and flooding (part 2) (Session DD 1.4)

Structure of the presentation

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- Motivation
- Goals
- Research framework
- Data and model evaluation and suitability
- Climate change (CC) impacts (high flow = O. de Keizer's follow-up presentation)
- Conclusions
- Outlook

Motivation for the RheinBlick2050 project

- Regional climate change does and will modify hydrological processes and the water balance and discharge in the Rhine River basin and its tributaries
- This has variable impacts, depending on respective sectors' sensitivities and vulnerabilities
- Decision makers need suitable information to develop adequate adaptation strategies
- Existing publications / projects exist, albeit often either
  - **Small regional climate change projection ensemble size**, potential undersampling of "true" bandwidth; difficult assessment of uncertainties, or
  - Focus often on **only on subcatchments**; methodologically difficult to combine, or
  - Missing link to **stakeholders** (i.e. water managers)
- Need for **common coordinated discharge projections for the complete catchment**
- The **CHR** has a coordinating role in hydrological research in the Rhine River catchments (joint research; exchange of data, methods, information; development of standardized procedures)
- Close linkage to and cooperation with the **ICPR / AG-H / EG Klima**; CHR specifically mentioned in ICPR's tasks in Rhine ministers conference communiqué of 2007 under topic "Climate change and its consequences"

Project goals

- Overall objective: **Assessment of regional climate change impacts on discharge in the Rhine River basin** ("classical" hydrological impact study)
- Goals and results
  1. Development of a **common, consistent research framework** across participating countries (5) and institutions (8); "common" = agreement on suitability of data, methods, models; "consistent" = data and models available for the complete catchment
  2. Creation (acquisition, pre-processing, evaluation, bias-correction) of state-of-the-art **regional climate change projection ensemble** for analyses and as forcing data to hydrological models to generate **specific discharge projections**
  3. Compilation of partly heterogeneous* information into **applicable information and quantifiable statements** through **scenario bandwidths and tendencies** of future changes in meteorological and hydrological **key diagnostics** (mean, low and high flow statistics) for **time-spans up to 2050 and 2100**

* "meta" project, based on existing ongoing projects, results and data of the partners (e.g. KLIWAS, CCHydro)

Research framework
Experiment design, data, modelling / processing chains

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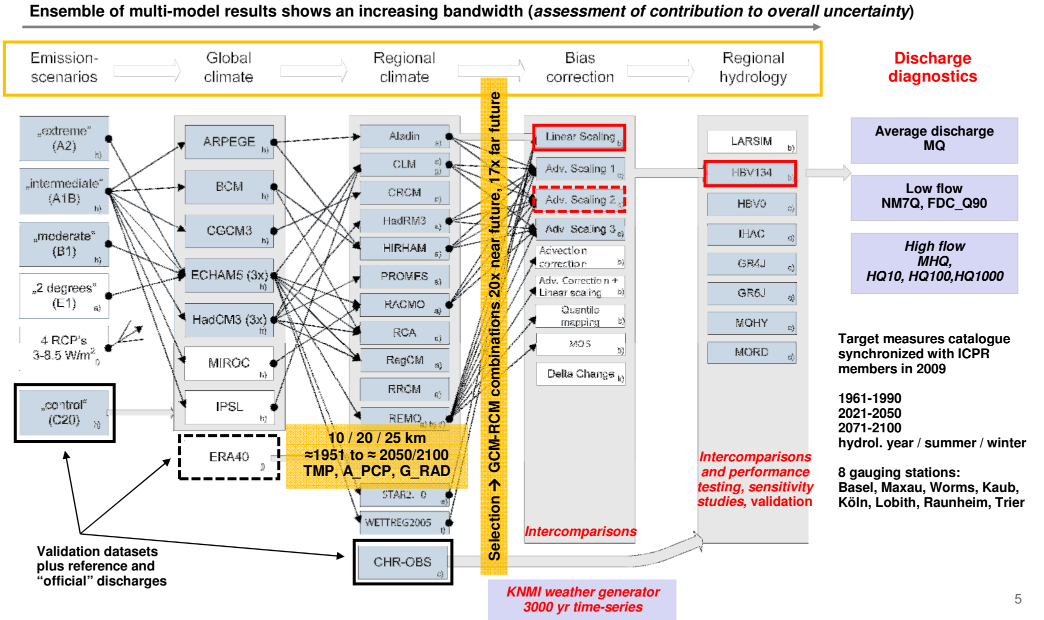

Research framework
Study area and setup of hydrological model HBV134

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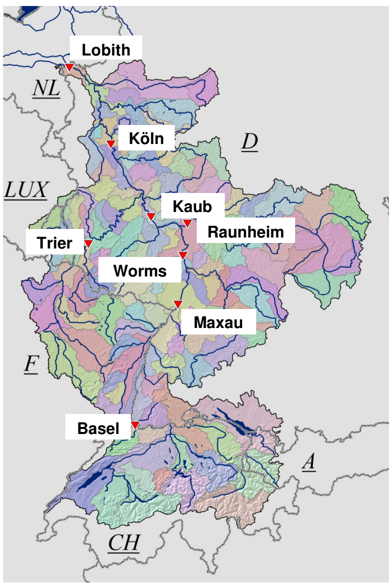

- HBV hydrological model for discharge projections
- Version: HBV-96, implemented by BfG and RWS-WD to Rhine River catchment
- Semi-distributed, 134 model catchments (HBV134)
- Daily time-step
- Inputs: precipitation, air temperature, potential evapotranspiration
- Limitations (excerpt)
  - Hydrometeorological reference datasets
  - Linear description of base flow
  - No lake retention, not too sensitive
  - Flood routing, no hydraulic model, no overtopping of dikes → only with HQx

Research framework
Results evaluation: “Scenario bandwidths and tendencies”

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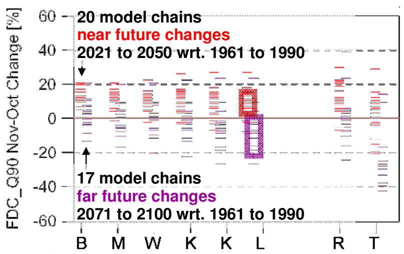
- ... Discharge projections → specific diagnostics → how to evaluate and communicate bandwidth?
- → **scenario bandwidths and tendencies**; combining qualitative and quantitative measures
  - Tendency: **direction of change** (increase / no tendency / decrease / no conclusion), 80% of ensemble members point into same direction
  - Bandwidth: **bandwidth of change**, [%], 80% of ensemble members are within that span



Gauging station	2021 to 2050	2071 to 2100
Basel	+5 to +15%	-5 to +15%
Maxau	+5 to +15%	+/-10
Worms	+5 to +15%	+/-10
Kaub	+5 to +15%	-10 to +5%
Köln	+5 to +15%	-10 to 0%
Lobith	+5 to +15%	-20 to 0%
Raunheim	+5 to +25%	+/-10
Trier	-5 to +15%	-40 to -25%

- Existing results and knowledge of all partners may be easily integrated; adjustable; extensible
- In line with “good practice“ recommendations of EU
- Checked with ICPR stakeholders for usability

Data and model evaluation and suitability
Selection and bias-correction of RCM runs

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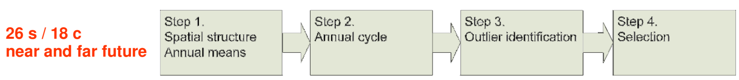
37 control simulations (s) considered in total various combinations (c)



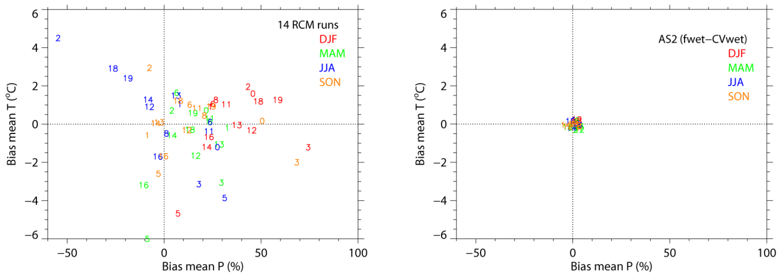
20 s / 16 c near future
17 s / 13 c far future

Through selection (before bias correction)
→ reduction of bandwidth

NO WEIGHING of RCM results

- Deviation of RCM results from observations (ctrl.)
- Hydrological models sensitive to such biases
- 4 bias-corrections methods are used
  - Linear scaling (meteorology / mean / low flow)
  - Non-linear scaling (high flow) → extreme multi-day precipitation

Effects of bias-correction: BEFORE / AFTER (TMP, A_PCP bias, 1961 to 1990, wrt. CHR_OBS, AS2 BC)



Data and model evaluation and suitability
Validation of HBV134 simulations, e.g. mean and low flow

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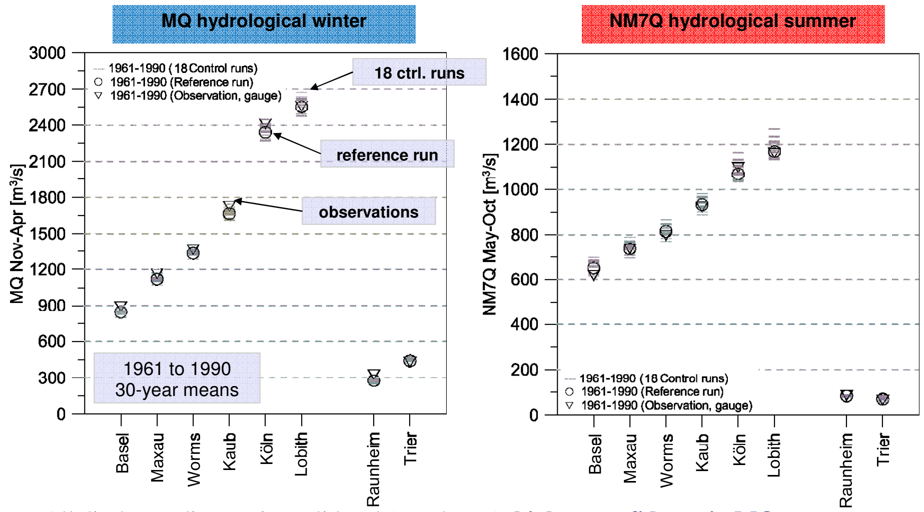

- All discharge diagnostics validated (not shown), **highest confidence in MQ**
- **Complete model chain** (C20→GCM→RCM→BC→HM) produces **reliable results**
- HM performance and uncertainty: **HBV134 most reliable**, errors < 5%, > 90% variance explained

CC impacts – Meteorological drivers, basin-wide

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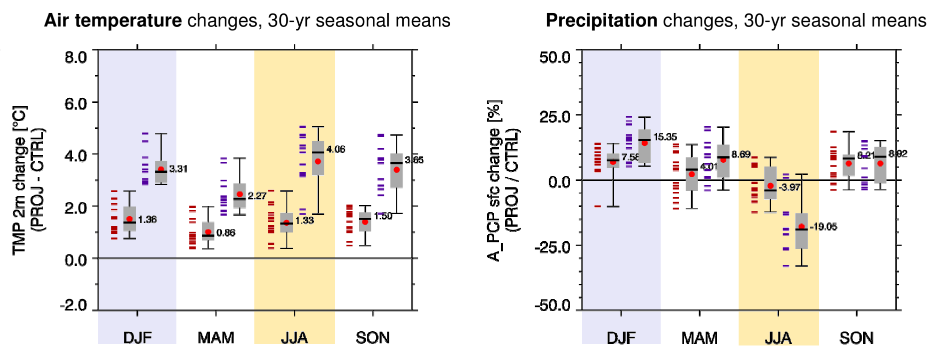

- **All seasons: increase of temperature, all spatial domains (slightly higher in South); more clearly defined in winter**
- **Wi: 0.5°C to 2.5°C near future; 2.5°C to 5.0°C far future**
- **Su: 0.0°C to 2.0°C near future; 2.5°C to 5.0°C far future**
- **Wi: increase of precipitation; 0% - 15% near future; up to 25% far future**
- **Su: decrease of 10% to 30% far future**
- **Sp/Su/Au: no clear tendency near future**
- **Spatially uniform in-/de-crease in near future; larger heterogeneity in South in far future**

CC impacts – *Mean flow* changes
Modified discharge regimes throughout the basin

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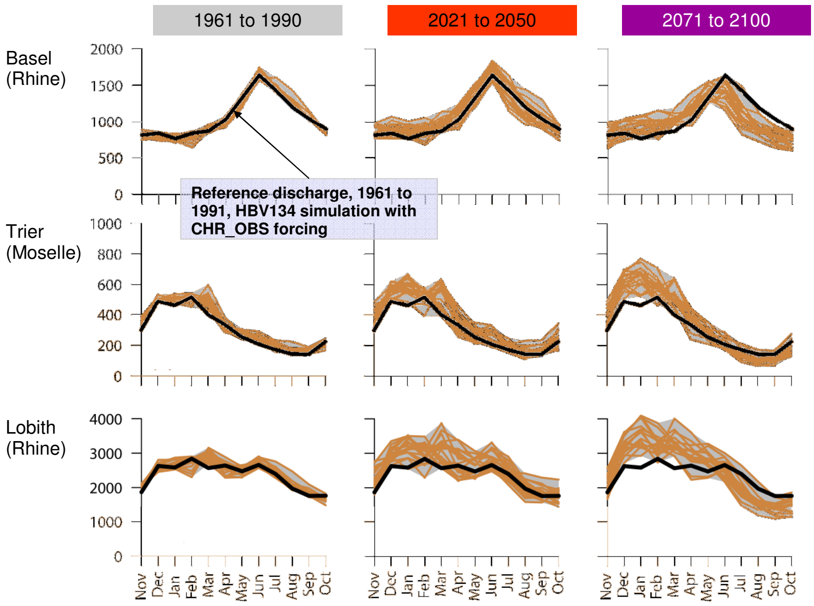
MQ [m³/s], 30-year long-term monthly mean discharge, annual cycles, Nov-Oct



More rainfall in Wi
Less snowcover / -storage
Shift in regime

Westerly flow
Adv. lows in Wi
More rainfall in Wi
Less rainfall in Su

Combined effects
Clear change signal

CC impacts – *Mean flow* changes
MQ changes, hydrological winter and summer

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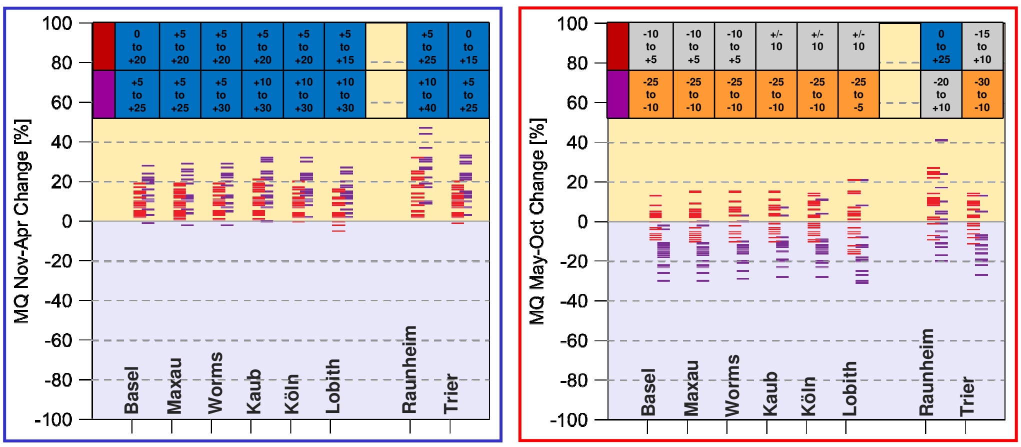
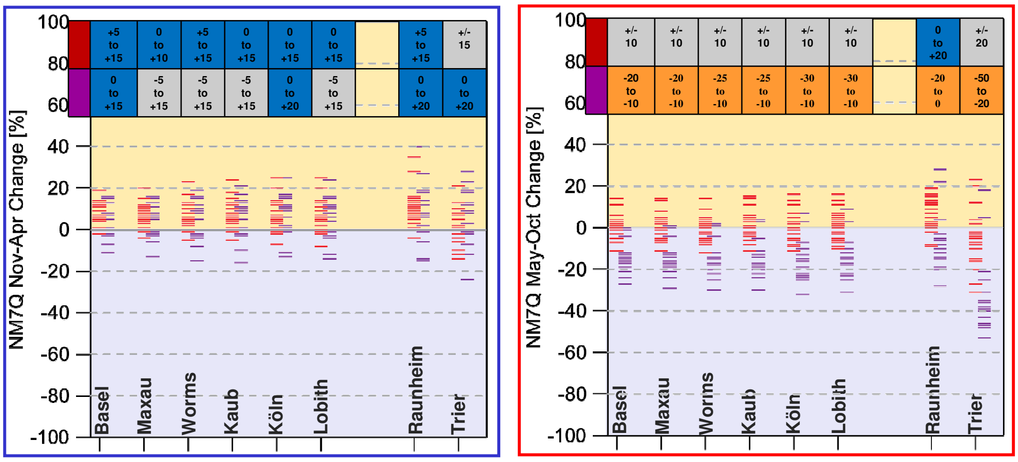
Projected relative changes of 30-year long-term mean **hydrological winter** / **summer MQ** and scenario bandwidths and tendencies



- **Wi: increase of mean discharge: near (0% to +25%), far (+5% to +40%) future**
- **Su: opposite tendency: decrease of 30% to 5% far future; upstream: more rainfall-dominated flow regime → more similar to regimes downstream; shift of maxima and minima**
- **Annual (not shown): increasing tendencies only for near future (Kaub, Köln, Lobith, Raunheim); in far future Wi and Su tendencies compensate each other**

CC impacts – *Low flow* changes
NM7Q changes, hydrological winter and summer

Projected relative changes of 30-year long-term mean **hydrological winter** / **summer NM7Q** and scenario bandwidths and tendencies INCREASE = LESS SEVERE LOW-FLOW CONDITIONS



- **Wi: increasing tendencies for near / far future (0% to 15%)**
- **Su: decrease of seasonal lowest 7-day mean discharge in far future (-30% to -10%)**

Conclusions

- A concerted, international view of regional climate change impacts on the discharge regime of the Rhine River is derived
- Individual results (**mean, low, high* flow**) have **different** magnitudes of **uncertainties and reliabilities** assigned
- Hydrological **projections and model chain components** are based on **a large proportion of currently available data** – which could still be extended (also in terms of gauges and analyses)
- Many **uncertainties and limitations still exist** → possible projections rather than predictions or forecasts
- Discharge analyses have been fed – among other sources – into the **political process at ICPR** where eventually **adaptation measures** shall be prepared among the riparian countries of the Rhine River

Outlook

- Still **many limitations in the framework**; how much bias-correction?, best approach for extreme discharge modelling?, "ideal" model chain in the near future?
- New model datasets, emission scenarios upcoming: **CMIP5, CORDEX** (IPCC 5 AR)
- Higher complexity in **earth-system models → increase in bandwidth**
- **Higher resolution RCM** climate change projections (capture surface heterogeneities)
- Still needed: further development of **bias-correction methods**, **objective RCM evaluation** criteria
- Improvements in **meteorological observation products** (reference datasets)
- Additional **hydrological model intercomparisons** are needed (analogue to RCM ensemble studies)
- **Extension of our hydrological modelling framework** (flood routing, flood retention) → important for adaptation, assessment of extreme discharges
- Extension of **uncertainty assessment**, contribution of model chain components to bandwidth
- Overall framework shall be used for further studies with extended modelling components

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CHR Climate change related reports via http://www.chr-khr.org

First CC impacts report ~ *outdated*

CHR report I-16
Grabs et al. (1996)

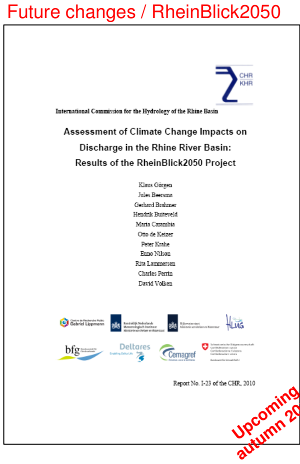
Impact of climate change on hydrological regimes and water resources management in the Rhine basin

Observed changes

CHR report I-22
Belz et al. (2007)

Das Abflussregime des Rheins und seiner Nebenflüsse im 20. Jahrhundert - Analyse, Veränderungen, Trends

Future changes / RheinBlick2050



Upcoming autumn 2010

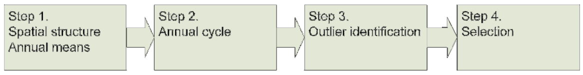
CHR report I-23
Görgen et al. (2010)

Assessment of Climate Change Impacts on Discharge in the Rhine River Basin: Results of the RheinBlick2050 project

Data and model evaluation and suitability
Selection and bias-correction of RCM runs

37 control simulations (s) considered in total various combinations (c)

26 s / 18 c near and far future

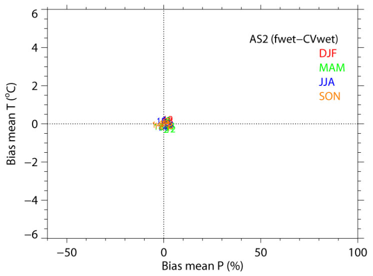


20 s / 16 c near future
17 s / 13 c far future

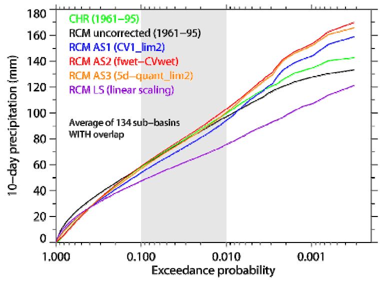
Through selection (before bias correction) → reduction of bandwidth

- Deviation of RCM results from observations (ctrl.)
- Hydrological models sensitive to such biases
- 4 bias-corrections methods are used
  - Linear scaling (meteorology / mean / low flow)
  - Non-linear scaling (high flow) → extreme multi-day precipitation

TMP, A_PCP bias, 1961 to 1990, wrt. CHR_OBS, AS2 BC



CDF, 10-day precipitation, DJF, HADCM3Q0_CLM_25



Structure of the presentation

- Motivation
- Goals
- Research framework
  - Data flow-path and modelling chains
  - Study area and setup of hydrological model HBV134
  - Scenario bandwidths and tendencies
- Data and model evaluation and suitability
  - Selection and bias-correction of RCM runs
  - Validation of HBV134 simulations
- Climate change (CC) impacts (high flow = O. de Keizer's follow-up presentation)
  - Meteorological drivers
  - Mean flow changes
  - Low flow changes
- Conclusions
- Outlook

Research framework
Study area; setup of hydrological model HBV134

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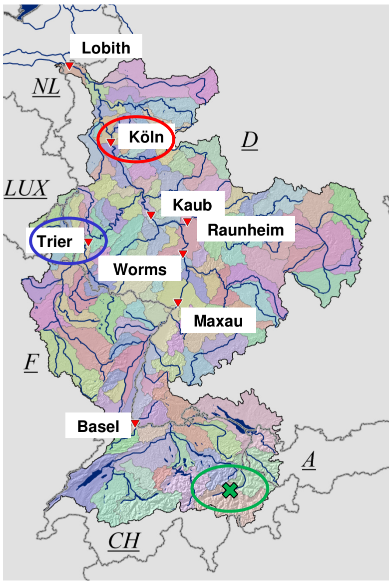

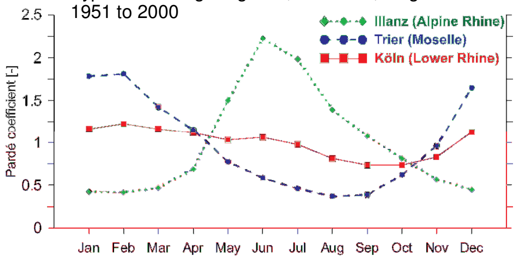

- HBV134 for discharge projections (HBV-96)
- Semi-distributed, 134 model catchments, daily
- Inputs: precip., air temp. , pot. evapotransp.
- Limitations
  - Hydrometeorological reference datasets
  - Linear description of base flow
  - No lake retention, not too sensitive
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Data and model evaluation and suitability
Selection of RCM runs

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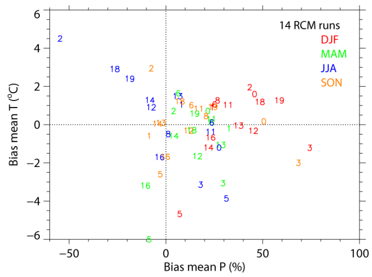
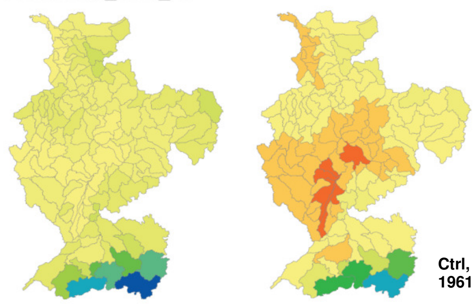
TMP, A_PCP bias, 1961 to 1990, wrt. CHR_OBS



HADCM3Q0_CLM_25 HADCM3Q16_HADRM3Q16_25



Ctrl, C20, 1961 to 1990

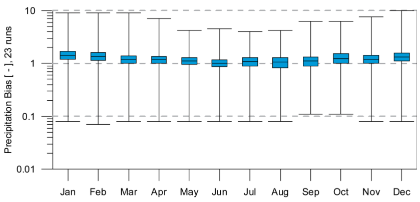
37 control simulations (s) considered in total various combinations (c)

26 s
18 c

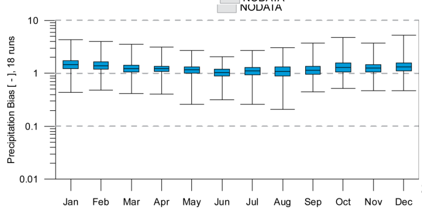
Step 1. Spatial structure Annual means → Step 2. Annual cycle → Step 3. Outlier identification → Step 4. Selection

P sum YEAR [mm]

26 s / 16 c near future
17 s / 13 c far future



Through selection (before bias correction) → reduction of bandwidth



Data and model evaluation and suitability
Bias-correction of RCM runs

- Deviation of RCM results from observations (ctrl.)
- Hydrological models sensitive to such biases
- 4 bias-corrections methods are used
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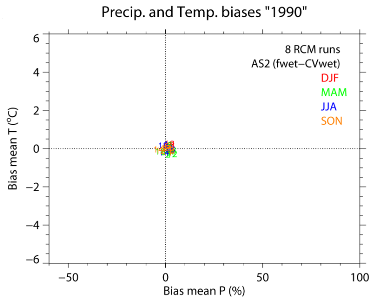
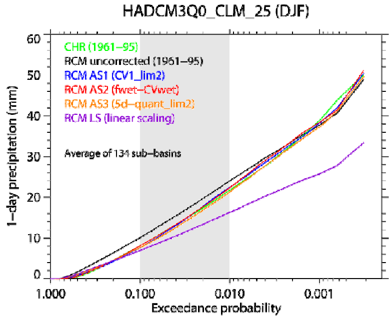
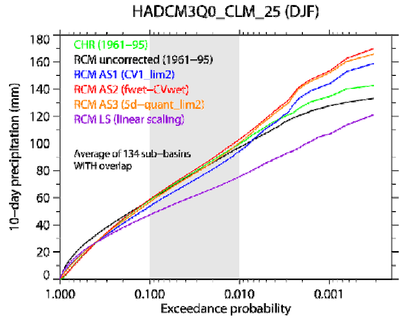
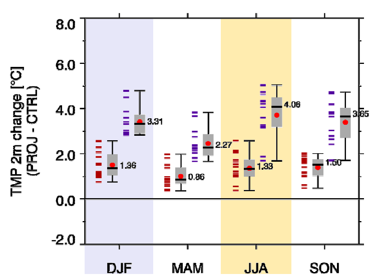




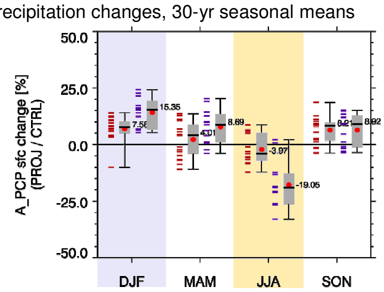


Results – Meteorological changes

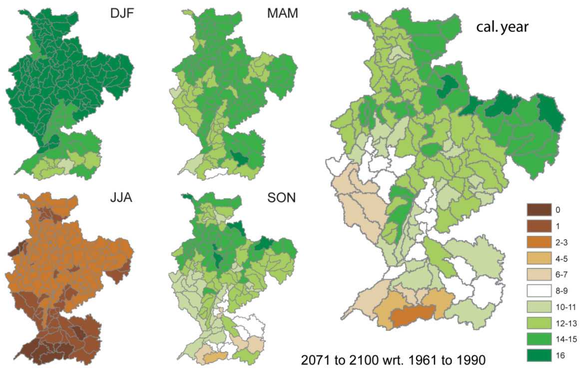
Basin-wide air temperature changes
30-yr seasonal means



Precipitation changes, 30-yr seasonal means



Robustness of A-PCP change signals: # proj. with A-PCP increase



- Increase of TMP in all seasons and subsets (slightly higher in South); more clearly defined signal in winter; 0.5°C - 2.5°C Wi & 0.0°C - 2.0°C Su / near future; 2.5°C - 5.0°C Wi & 2.5°C - 5.0°C Su / far future
- Increase of A-PCP in Wi, 0% - 15% near, up to 25% far future; no clear tendency in near future, decrease of 10% - 30% / far future; spatially uniform in-/de-crease in near future; larger heterogeneity in South in far future

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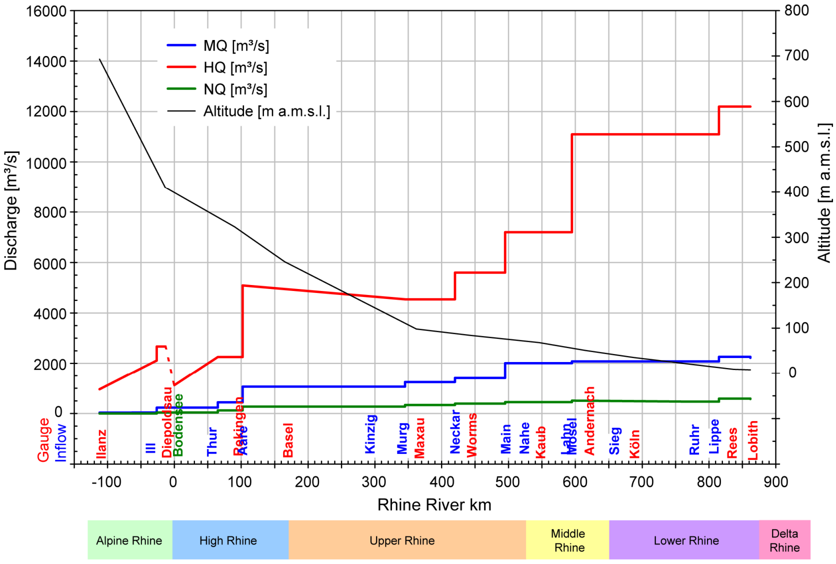

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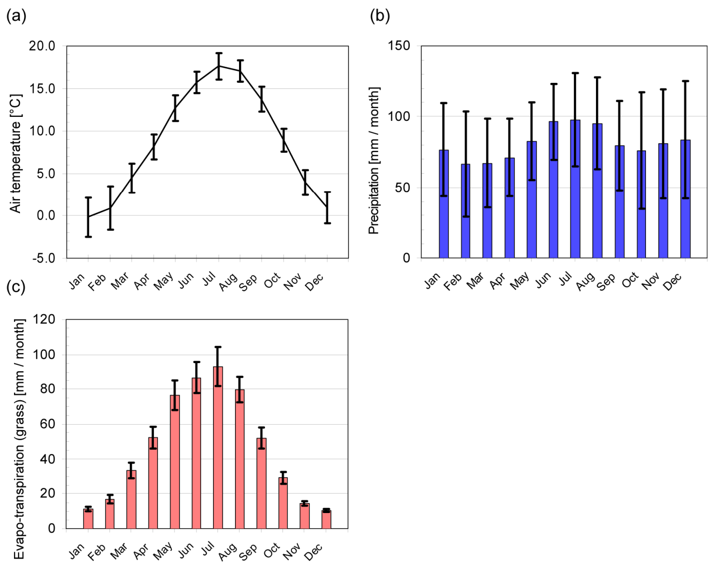

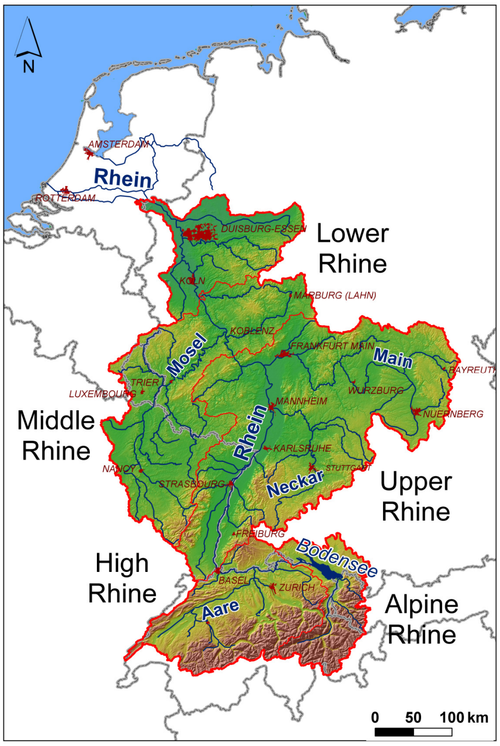
N
Rhein
AMSTERDAM
ROTTERDAM
DUISBURG-ESSEN
Lower
Rhine
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MARBURG (LAHN)
KOBLENZ
FRANKFURT MAIN
Main
Mosel
BAYREUTH
TRIER
LUXEMBOURG
WÜRZBURG
MANNHEIM
NUERNBERG
Middle
Rhine
Rhein
KARLSRUHE
NANCY
STUTTGART
STRASBOURG
Neckar
Upper
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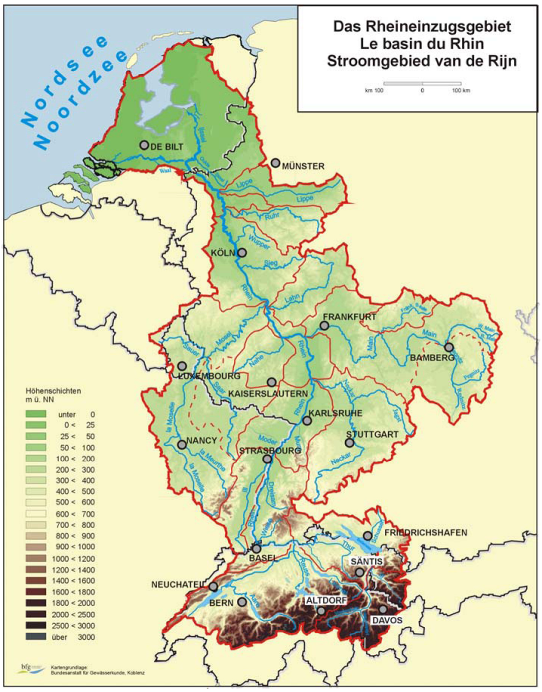
FREIBURG
Bodensee
High
Rhine
BASEL
ZÜRICH
Aare
Alpine
Rhine
0 50 100 km


Das Rheineinzugsgebiet
Le basin du Rhin
Stroomgebied van de Rijn
Nordsee
Noordzee
DE BILT
MÜNSTER
KÖLN
FRANKFURT
BAMBERG
LUXEMBOURG
KAISERSLAUTERN
KARLSRUHE
STUTTGART
NANCY
STRASBOURG
FRIEDRICHSHAFEN
BASEL
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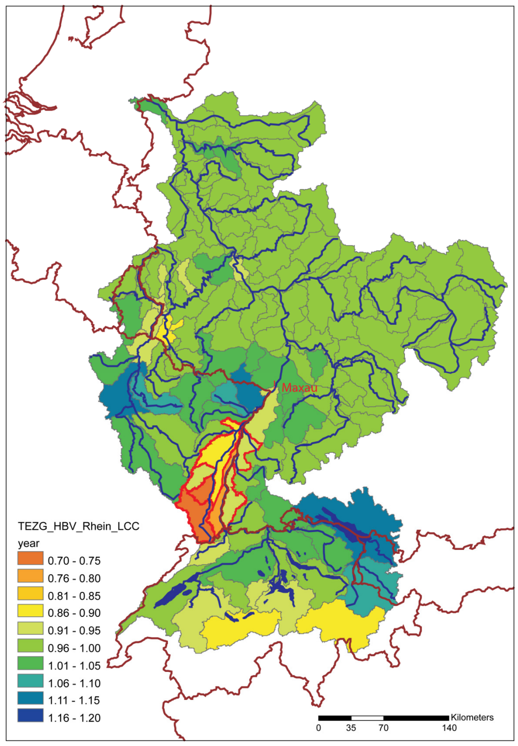
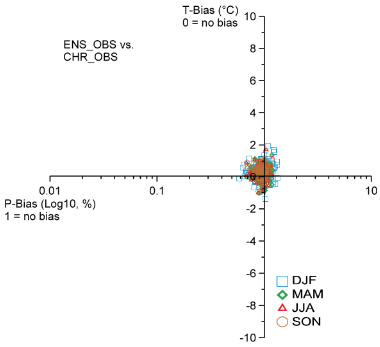

Maxau
TEZG_HBV_Rhein_LCC
year
0.70 - 0.75
0.76 - 0.80
0.81 - 0.85
0.86 - 0.90
0.91 - 0.95
0.96 - 1.00
1.01 - 1.05
1.06 - 1.10
1.11 - 1.15
1.16 - 1.20
0 35 70 140
Kilometers

CHR
KHR


T-Bias (°C)
0 = no bias
ENS_OBS vs.
CHR_OBS
10
8
6
4
2
0
-2
-4
-6
-8
-10
0.01
0.1
10
P-Bias (Log10, %)
1 = no bias
DJF
MAM
JJA
SON

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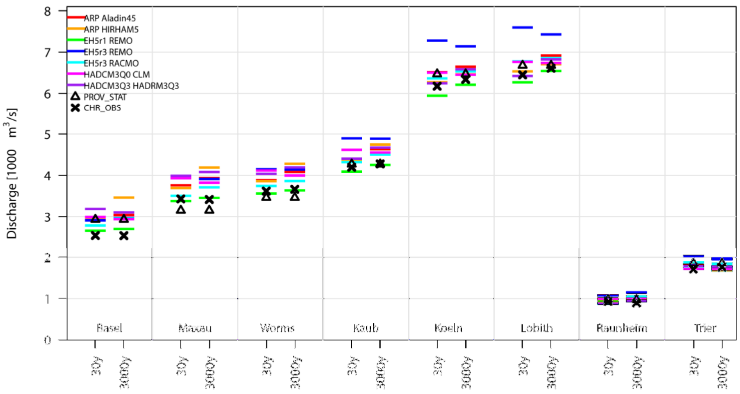
MHQ (1961 – 1990)



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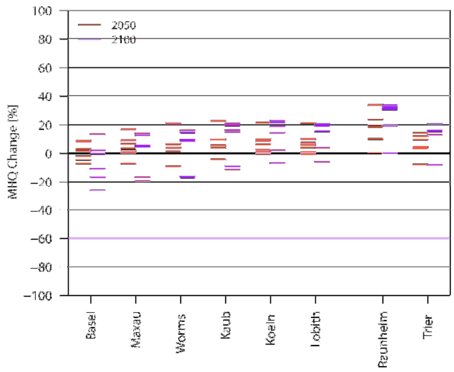
KHR



Comparison of HBV134-simulations with observed statistics

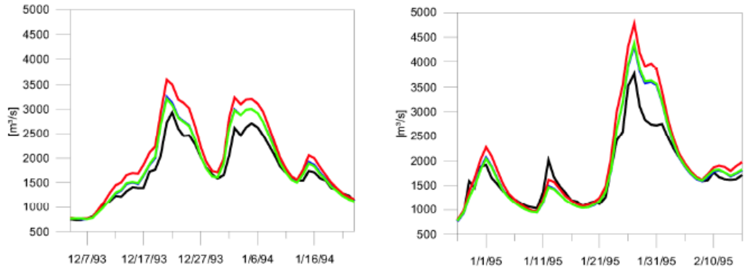


Figure 3-29: Flood events 1993/1994 and 1994/1995 at Maxau: Observed discharge (black line), simulated discharge by HBV134_BFG forced by input 1 (red line), input 2 (blue line) and by input 3 (green line). Datasource: BfG

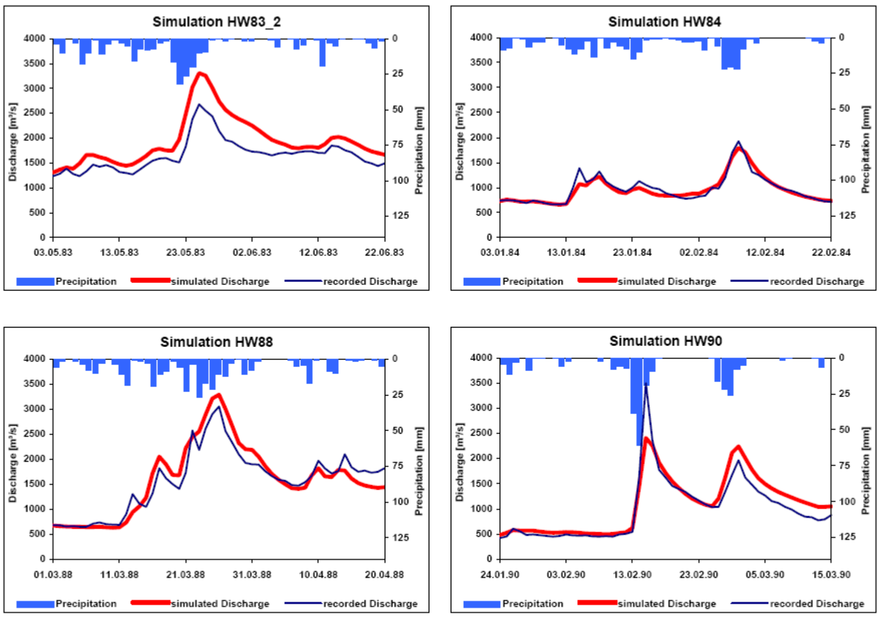
Table 3-12: Deviations of discharge as simulated by HBV134_BfG and observations for the flood events 1993/1994 and 1994/1995 at gauge Maxau.

Date of observed peak discharge	Forcing: input 1		Forcing: input 2		Forcing: input 3	
	Deviation of peak [%]	Delay of peak [d]	Deviation of peak [%]	Delay of peak [d]	Deviation of peak [%]	Delay of peak [d]
1993-12-22	22.7	-1	11.1	-1	9.3	-1
1994-01-02	23.4	0	14.2	0	13.6	0
1994-01-05	18.2	0	10.9	0	10.7	0
1995-01-27	26.6	0	15.1	0	16.2	0

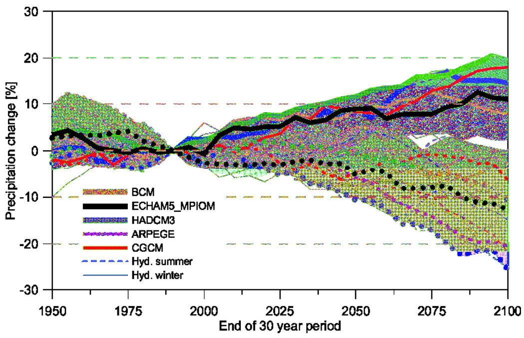
Performance of HBV134
BfG-1451 Technical Report, Koblenz, 2005 “Hydrological Modelling in the River Rhine Basin” (daily HBV model), examples

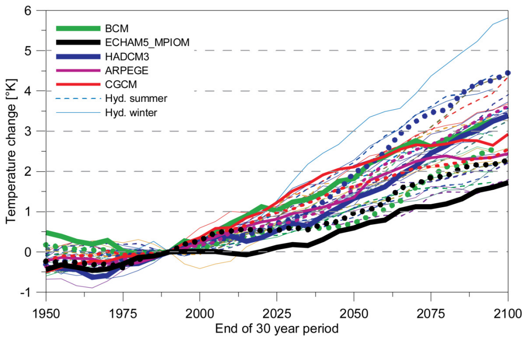
Basel

Reproduction of specific flood events

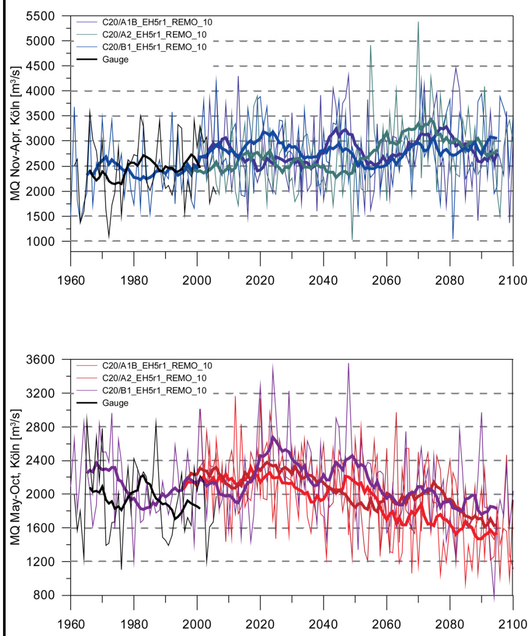


Uncertainties
SRES → GCM → RCM → BC → EVAP → WBM

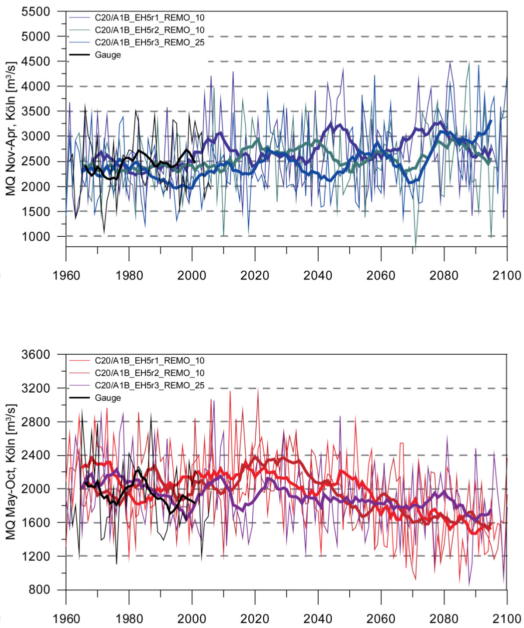


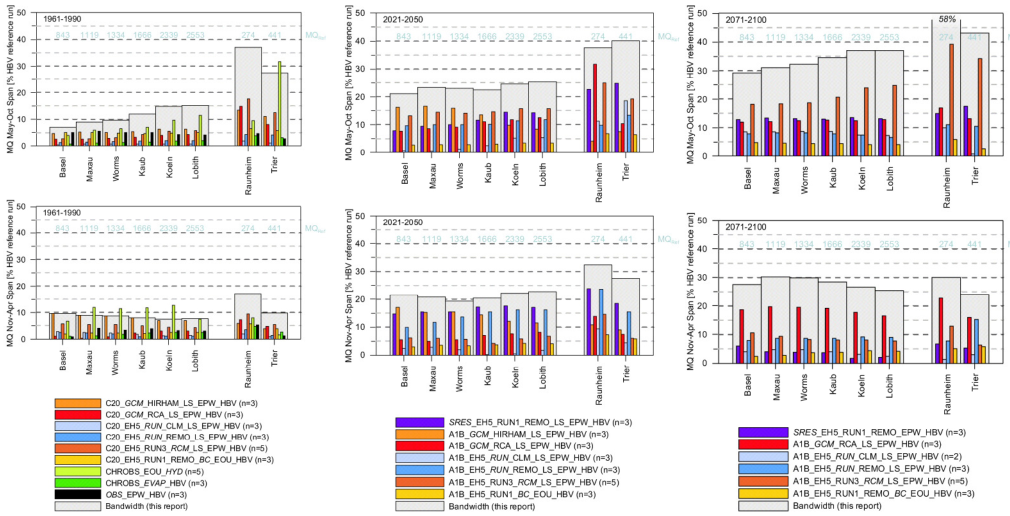


SRES var.

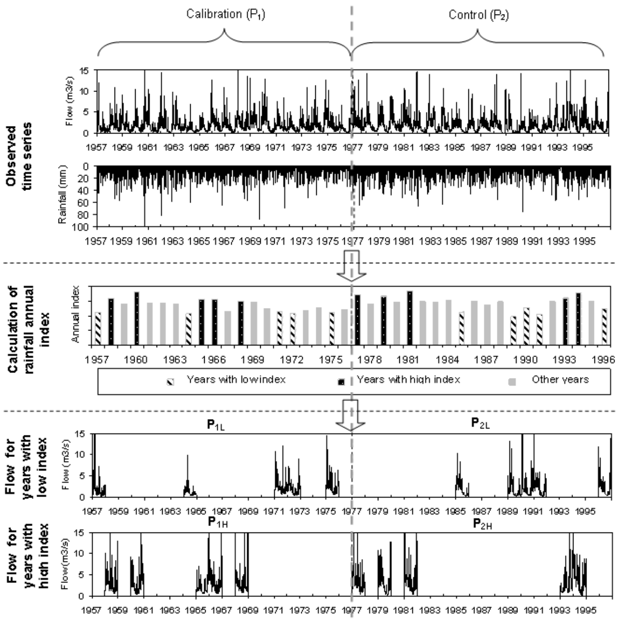


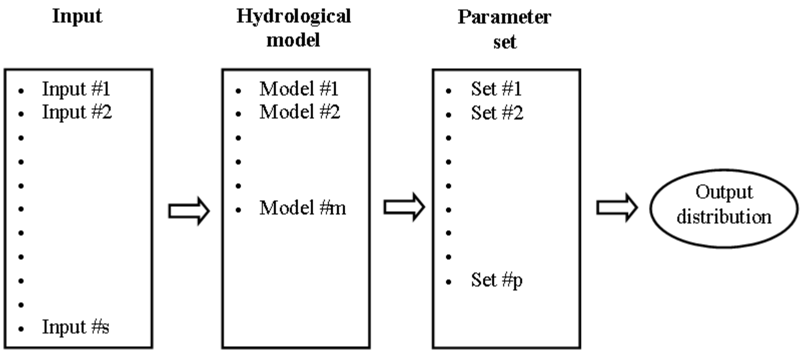
GCMvar.



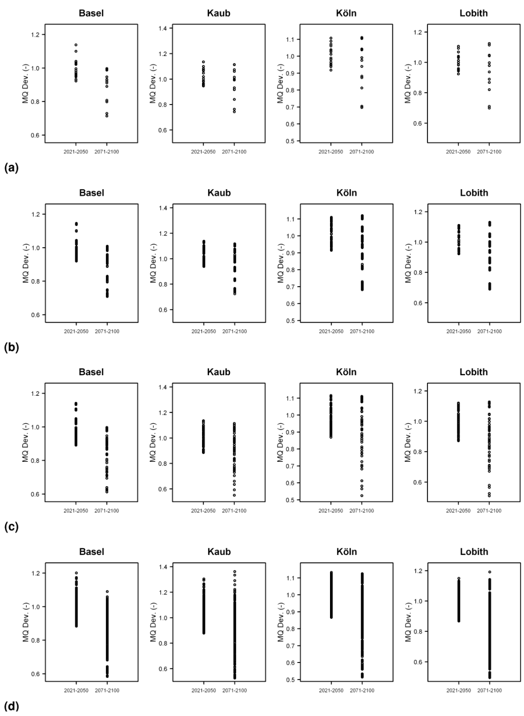


Hydrological model performance and uncertainty analysis
Input / structural / parameter uncertainty





MQ
Parameter tests



Atmospheric data processing
Bias-correction methods

Table 2-4: Characteristics of different bias-correction methods applied to precipitation fields of RCMs. See text for details. LS is also used to correct fields of sunshine duration or global radiation. The spatial domain is always the 134 HBV model catchments.

Short	Method	Equation	Temporal domain	Statistical domain	Applied for
LS	Linear Scaling	$P^* = a \times P$	Monthly	Mean of P amount	Mean and low flow
AS1	Advanced Scaling1 "cv1_lim2"	$P^* = a \times P^b$	5-day periods (including data from 30 days before and after)	Mean and coefficient of variation of P amount. For large daily sums (P > 99th percentile) linear scaling based on average excess	Mean flow and occasionally high flow
AS2	Advanced Scaling 2 "fwet_cvwet"	$P^* = a \times P^b$	Monthly	Mean and coefficient of variation of daily P amount on P days (days >0.05 mm frequency corrected)	Mean and high flow
AS3	Advanced Scaling 3 "5d_quant_lim 2"	$P^* = a \times P^b$	5-day periods (including data from 30 days before and after)	60. and 95. quantile of 5 day P amount. For large 5-day sums (P5d > 95th quantile) linear scaling based on average excess	Mean and occasionally high flow

Atmospheric data processing
Bias-correction methods

Table 2-5: Characteristics of different bias-correction methods applied to temperature fields of RCMs. See text for details. The spatial domain is always the 134 HBV model catchments.

Short	Method	Equation	Temporal domain	Statistical domain	Applied for
LS	Linear Scaling	$T^* = T(t) + (T_{obs} - T_{C20})$	Monthly	Mean of T	Mean and low flow
AS1 AS2 AS3	Advanced Scaling 1 to 3	$T^* = \frac{\sigma_{obs}}{\sigma_{C20}}(T(t) - \overline{T}_{C20}) + \overline{T}_{obs}$	5-day periods (including data from 30 days before and after)	Mean and standard deviation of T	Mean and high flow