RheinBlick2050

Joint Climate and Discharge Projections for the Rhine

Overview

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Structure of the presentation

- 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

Ensemble of multi-model results shows an increasing bandwidth (assessment of contribution to overall uncertainty)

Target measures catalogue synchronized with ICPR members in 2009
1961-1990
2021-2050
2071-2100
hydrol. year / summer / winter
8 gauging stations:
Basel, Maxau, Worms, Kaub, Köln, Lobith, Raunheim, Trier

Research framework
Study area and setup of hydrological model HBV134

- 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”

• ... 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

• 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

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

26 s / 16 c near and far future

• 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

- 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

- 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-/decrease in near future; larger heterogeneity in South in far future
CC impacts – Mean flow changes
Modified discharge regimes throughout the basin

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

- Basel
  - 1961 to 1990
  - 2021 to 2050
  - 2071 to 2100

- Trier
  - 1961 to 1990
  - 2021 to 2050
  - 2071 to 2100

- Lobith
  - 1961 to 1990
  - 2021 to 2050
  - 2071 to 2100

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

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 \(\rightarrow\) 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) \(\rightarrow\) 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

International Commission for the Hydrology of the Rhine Basin
CHR Climate change related reports via http://www.chr-khr.org

First CC impacts report – outdated
CHR report I-16
Grabs et al. (1998)
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
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)

- 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

Through selection (before bias correction) → reduction of bandwidth

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- Goals
- Research framework
  - Data flow-path and modelling chains
  - Study area and setup of hydrological model HBV134
  - Scenario bandwidths and tendencies
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  - 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

- 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
  - Flood routing, no hydraulic model, no overtopping of dikes → only with HQx

Data and model evaluation and suitability
Selection of RCM runs

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

26 s  18 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.)
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Results – Meteorological changes

Basin-wide air temperature 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-/decrease in near future; larger heterogeneity in South in far future
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.

<table>
<thead>
<tr>
<th>Date of observed peak discharge</th>
<th>Deviation of peak [%]</th>
<th>Delay of peak [d]</th>
<th>Deviation of peak [%]</th>
<th>Delay of peak [d]</th>
<th>Deviation of peak [%]</th>
<th>Delay of peak [d]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993-12-22</td>
<td>22.7</td>
<td>-1</td>
<td>11.1</td>
<td>-1</td>
<td>9.3</td>
<td>-1</td>
</tr>
<tr>
<td>1994-01-02</td>
<td>23.4</td>
<td>0</td>
<td>14.3</td>
<td>0</td>
<td>13.6</td>
<td>0</td>
</tr>
<tr>
<td>1994-01-05</td>
<td>18.2</td>
<td>0</td>
<td>10.9</td>
<td>0</td>
<td>10.7</td>
<td>0</td>
</tr>
<tr>
<td>1995-01-27</td>
<td>28.6</td>
<td>0</td>
<td>15.1</td>
<td>0</td>
<td>16.2</td>
<td>0</td>
</tr>
</tbody>
</table>

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

MQ
### 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 catchment.

<table>
<thead>
<tr>
<th>Short Method</th>
<th>Equation</th>
<th>Temporal domain</th>
<th>Statistical domain</th>
<th>Applied for</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS</td>
<td>$P' = a \times P$</td>
<td>Monthly</td>
<td>Mean of $P$ amount</td>
<td>Mean and low flow</td>
</tr>
<tr>
<td>AS1</td>
<td>$P' = a \times P^b$</td>
<td>5-day periods (including data from 30 days before and after)</td>
<td>Mean and coefficient of variation of $P$ amount: For large daily sums ($P &gt; 99%$ percentile) linear scaling based on average excess</td>
<td>Mean flow and occasionally high flow</td>
</tr>
<tr>
<td>AS2</td>
<td>$P' = a \times P^b$</td>
<td>Monthly</td>
<td>Mean and coefficient of variation of daily $P$ amount on $P$ days (days &gt;0:05 mm frequency corrected)</td>
<td>Mean and high flow</td>
</tr>
<tr>
<td>AS3</td>
<td>$P' = a \times P^b$</td>
<td>5-day periods (including data from 30 days before and after)</td>
<td>60 and 99 quantile of 5 day $P$ amount: For large 5-day sums ($P5d &gt; 99th$ quantile) linear scaling based on average excess</td>
<td>Mean and occasionally high flow</td>
</tr>
</tbody>
</table>

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**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 catchment.

<table>
<thead>
<tr>
<th>Short Method</th>
<th>Equation</th>
<th>Temporal domain</th>
<th>Statistical domain</th>
<th>Applied for</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS</td>
<td>$T' = T(t) + (T_{th} - T_{30})$</td>
<td>Monthly</td>
<td>Mean of $T$</td>
<td>Mean and low flow</td>
</tr>
<tr>
<td>AS1, AS2, AS3</td>
<td>$T' = \frac{\partial T(t)}{\partial T_{30}} (T(t) - T_{30}) + T_{th}$</td>
<td>5-day periods (including data from 30 days before and after)</td>
<td>Mean and standard deviation of $T$</td>
<td>Mean and high flow</td>
</tr>
</tbody>
</table>