Hydrological modelling of alpine headwaters using centurial glacier evolution, snow and long-term discharge dynamics

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Study Aim

Modelling **daily streamflow Q** and the contributions of **ice & snow melt** for the River Rhine's glaciated headwater tributaries **over the last century** (1901–2006), a period characterised by significant glacier retreat.

Catchments

HBV-light alpine+ Model

HBV-light software
www.geo.uzh.ch/en/units/h2k/services/hbv-model/

Recent **extensions** tailored to study requirements:

- Snow melt
  - Aspect factor
  - Seasonally varying degree-day factor
- Conceptual representation of **snow redistribution**
- **Glacier modelling**
  - Transient glacier **area adjustment** (yearly steps)
  - Seasonally evolving glacier runoff response
- Differentiation of snow & ice melt Q-components

Data

Precipitation

- Gridded data of daily P sums for 1901–2006 (HYRAS data + analog day resampling for 1901-1950)
- **Wind drift correction** (based on Sevruk, 1989)
- **Factor correction** based on a **water balance assessment** using available Q-obs- data

➡ **Fixed** (not varied in calibration)

Streamflow

- 25 catchments: no Q-obs-data
- **24** catchments: **time series differing in timing and length**

Coverage of 1901-2006 through available Q obs time series from 24 catchments

➡ Calibration criteria: **3 efficiency criteria**

Snow

- **Gridded snow water equivalent** (SWE) **climatology** (1x1km)
- **Daily** SWE for the winter months (**Nov to May**) from Nov-1 **1971 to** Dec-31 **2006**
- Source: WSL–Institute for Snow and Avalanche Research **SLF**, Davos, Switzerland

➡ Calibration criteria: **SCA** (fraction of snow covered area) & **SWE** (mean of elev. zone **2000–2500m asl**)

Glaciers

Glacier outlines from available glacier inventories for the years of 1973 and 2003 and from digitised historical maps for the status around 1900 and around 1940

➡ Calibration criteria: glacier **volume changes** derived from maps & volume-area scaling

Calibration

- Optimization: genetic algorithm tool
- 10 calibrations (à 3000 runs)
- Calibration period: 1901-2006
- Weighted objective function:
  - **Glacier volume** changes → **25%** (Glacier benchmarks)
  - Mean **SWE** of elevation zone 2000 – 2500m asl: mean absolute error → **15%**
  - **SCA**: RMSE → **10%** (SLF snow data)
  - Efficiency for **ln(Q)** → **15%**
  - Seasonal eff. Q(**Jun-Sep**) → **15%**
  - **Lindstrom** efficiency* → **20%** (Q-obs-data)

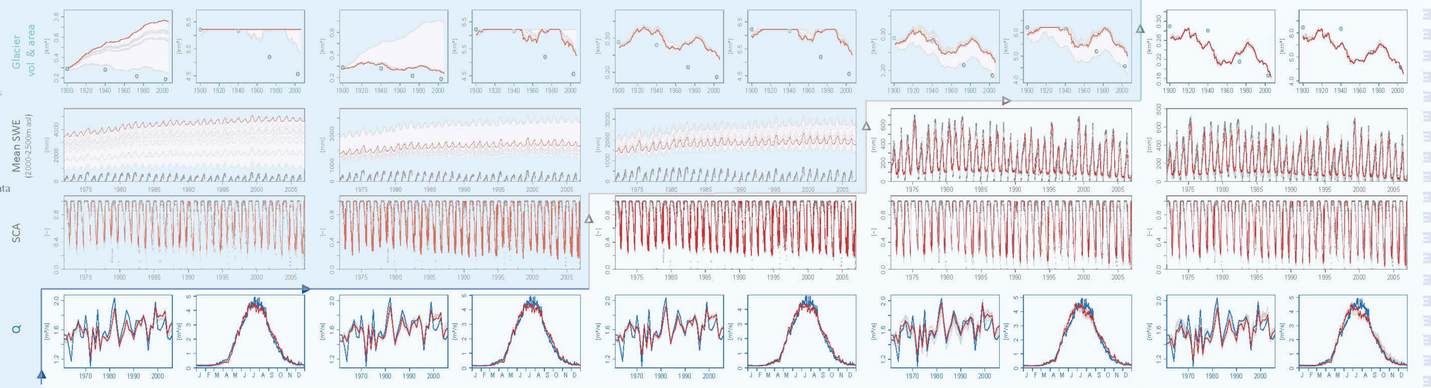
100%

* Combination of Nash-Sutcliffe-Eff. & Volume error

Calibration Results: Example Alpbach Catchment

Simulation best calibration parameter set — Simulations other 9 calibration parameter sets (Range from all 10 simulations)

using: only Q (Lindstrom Eff.) | all 3 Q efficiency criteria | adding SCA | adding SWE | adding glacier volumes



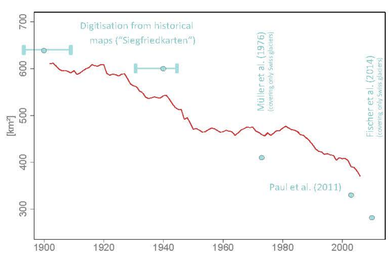
Key Challenges & Objectives

- **Scales**
  49 catchments, over > 100 years & daily time steps
- Modelling **ungauged catchments**
- **Alpine setting**
  - High complexity and spatial variability
  - Glaciers as additional (long-term) storage elements
  - → High **relevance of equifinality issues**
  - Poor availability of ground-based data
  - → **Uncertainty of input & limitations for calibration**

➡ **Find adequate calibration criteria** using observations which cover all catchments and the centurial period

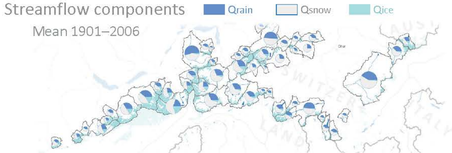
Results: All catchments

Simulated glacier area vs. survey data

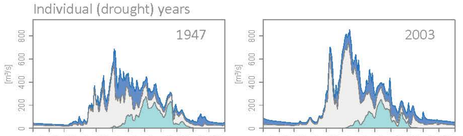


Streamflow components Qrain Qsnow Qice

Mean 1901–2006



Individual (drought) years



Conclusions

Only by incorporating multiple criteria into calibration a reasonable agreement of Q, snow and glacier dynamics with observations could be achieved over the centurial simulation period:

- Resulting parameter sets are more robust in a long-term climate variability context when using glacier change criteria.
- Possibility to calibrate snow and glacier parameters is crucial for modelling ungauged catchments.
- Limitations are evident in snow melt simulation beyond May when observational snow data were lacking.

Credits

***BAFU** (Swiss Federal Office for the Environment) for Q data ***SLF,** Tobias Jonas & Nena Griessinger for SWE data set ***Matthias Huss** (Université Fribourg / ETH Zurich) for glacier data & helpful advise ***DWD/BfG**: HYRAS data set ***HYDRON project partners**, Kai Gerlinger, Nicole Henn & Mario Böhm for help with precipitation correction ***Authors of glacier inventories**: Fischer et al. (2014), Müller et al. (1976)/Maisch et al. (2000); Paul et al. (2011) ***Colleagues & students from Freiburg & Zurich** involved in project work: Damaris De, David Finger, Barbara Frielingsdorf, Andreas Steinbrich, Simon Etter, Claudius Fleischer, Juliane Schillinger, Maria Staudinger ***CHR/KHR** (International Commission for the Hydrology of the Rhine basin) for funding this work as part of the project *"Abflussanteile aus Schnee- und Gletscherschmelze im Rhein und seinen Zuflüssen vor dem Hintergrund des Klimawandels (ASG Rhein)"*

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