CHR
KHB

Internationale Kommission für die Hydrologie des Rheingebietes

International Commission for the Hydrology of the Rhine Basin

Impact of climate change on the rain, snow and glacier melt components of streamflow of the river Rhine and its tributaries

Synthesis report

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Report No. I-28 of the CHR

ASG Qice, Qsnow, Qrain:

modelling streamflow components in the Rhine's headwaters with a modified HBV model

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Markus Weiler, and Kerstin Stahl

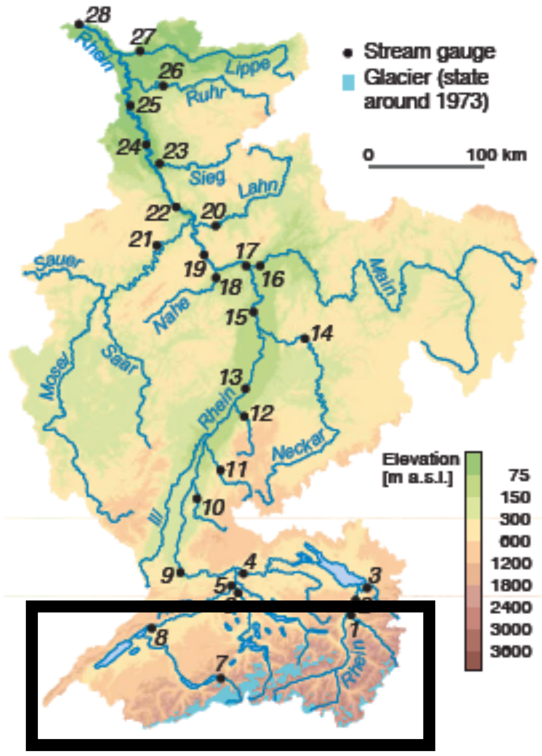
CHR Symposium 1. + 2. June 2022
in Olten, Switzerland

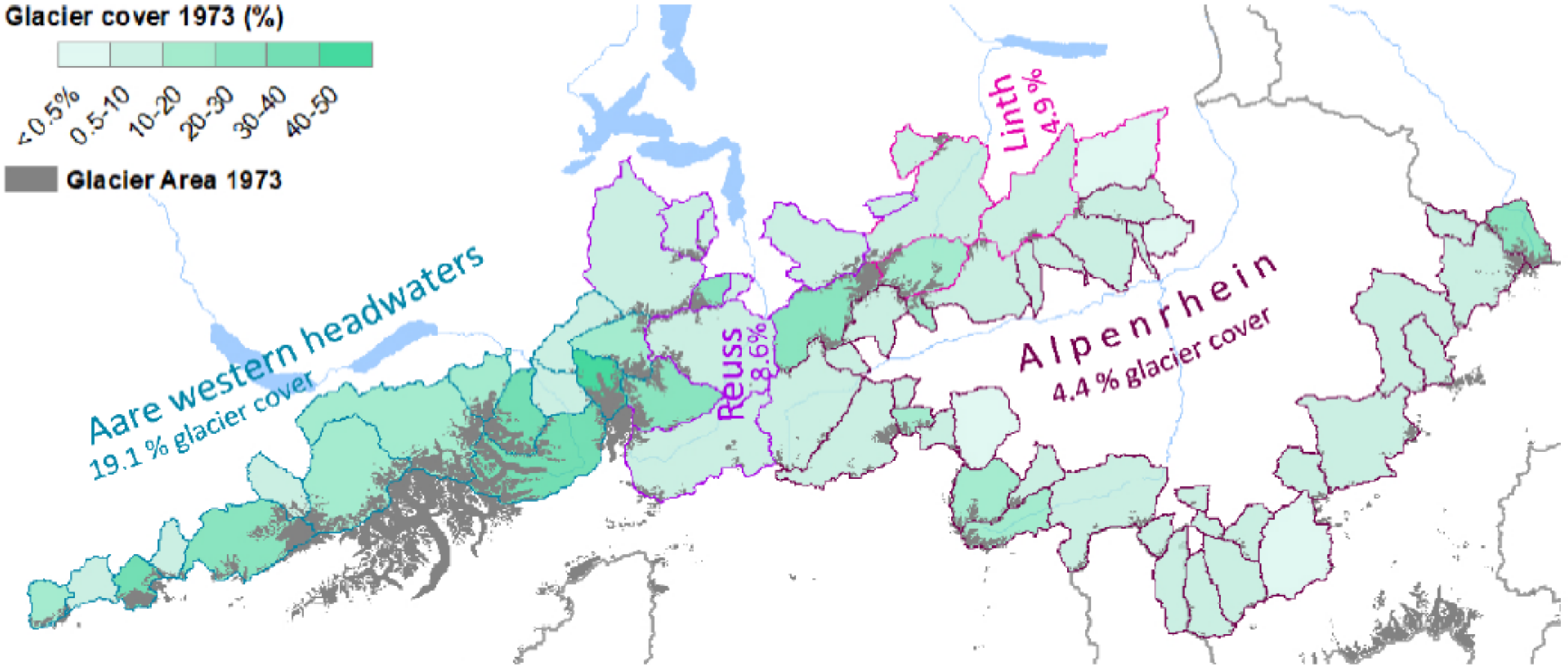
Universität Zürich[UZH]

HYDRON UMWELT und WASSERWIRTSCHAFT

UNI FREIBURG

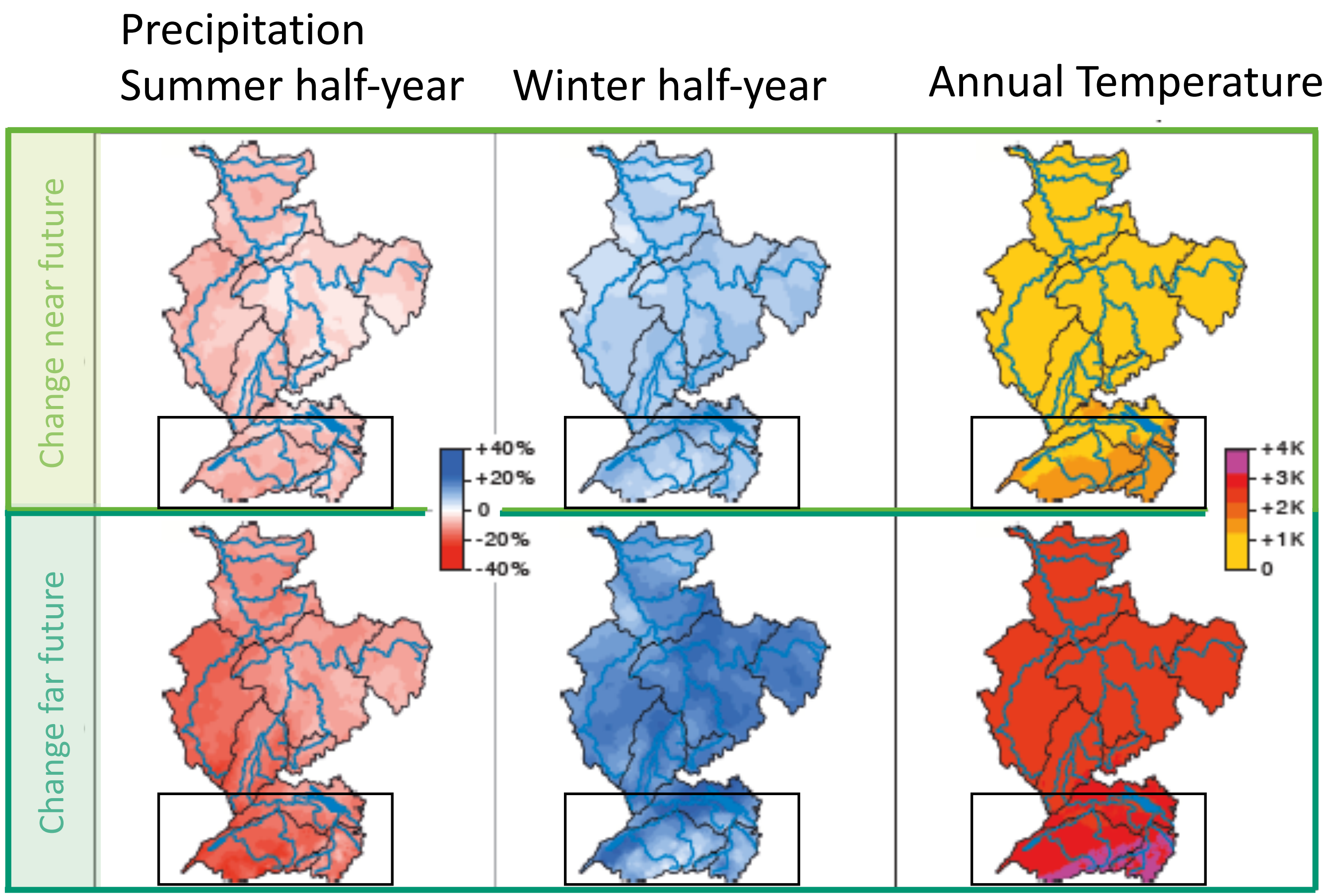
66 glacierized headwater catchments





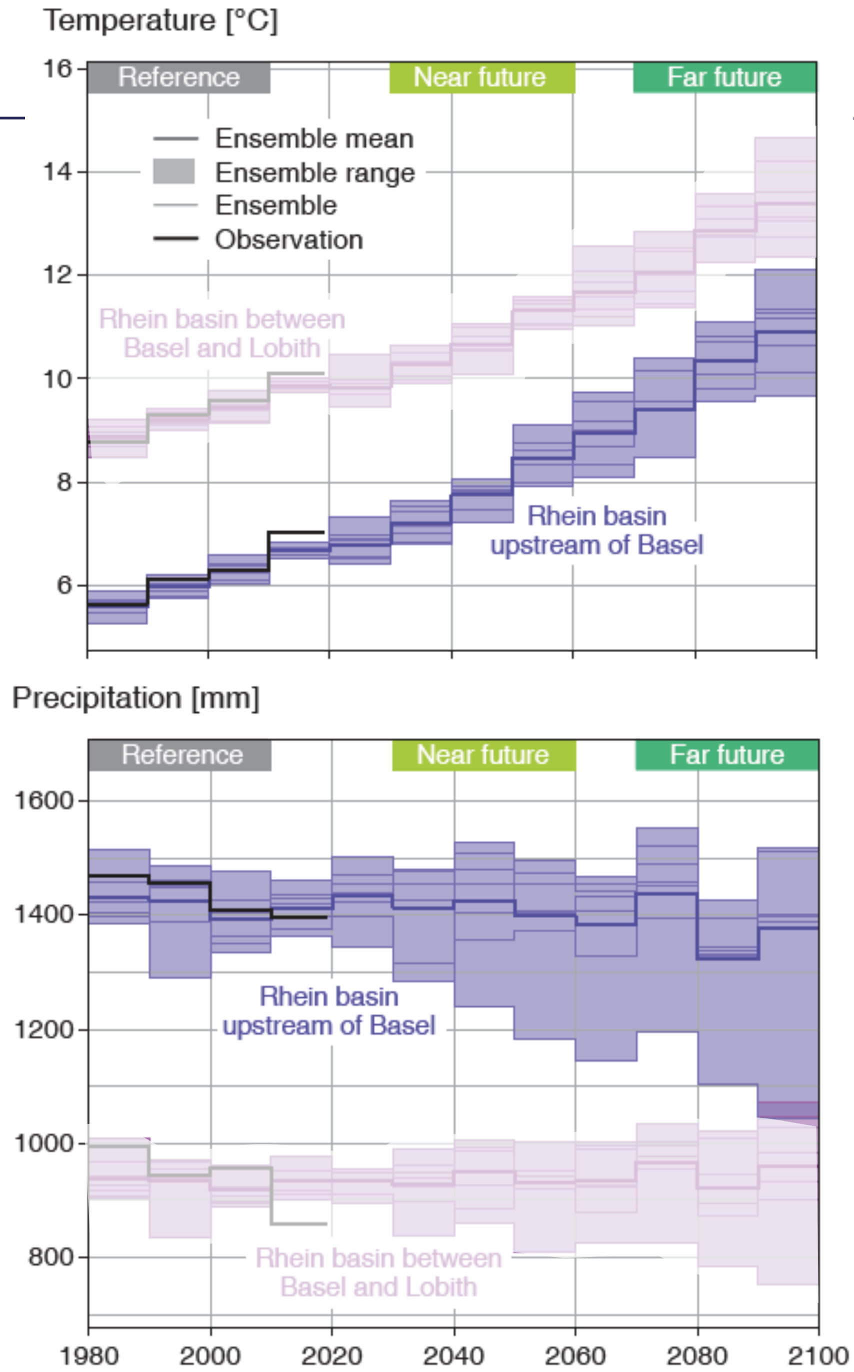
Projected climate in the Alps - RCP 8.5

Introduction

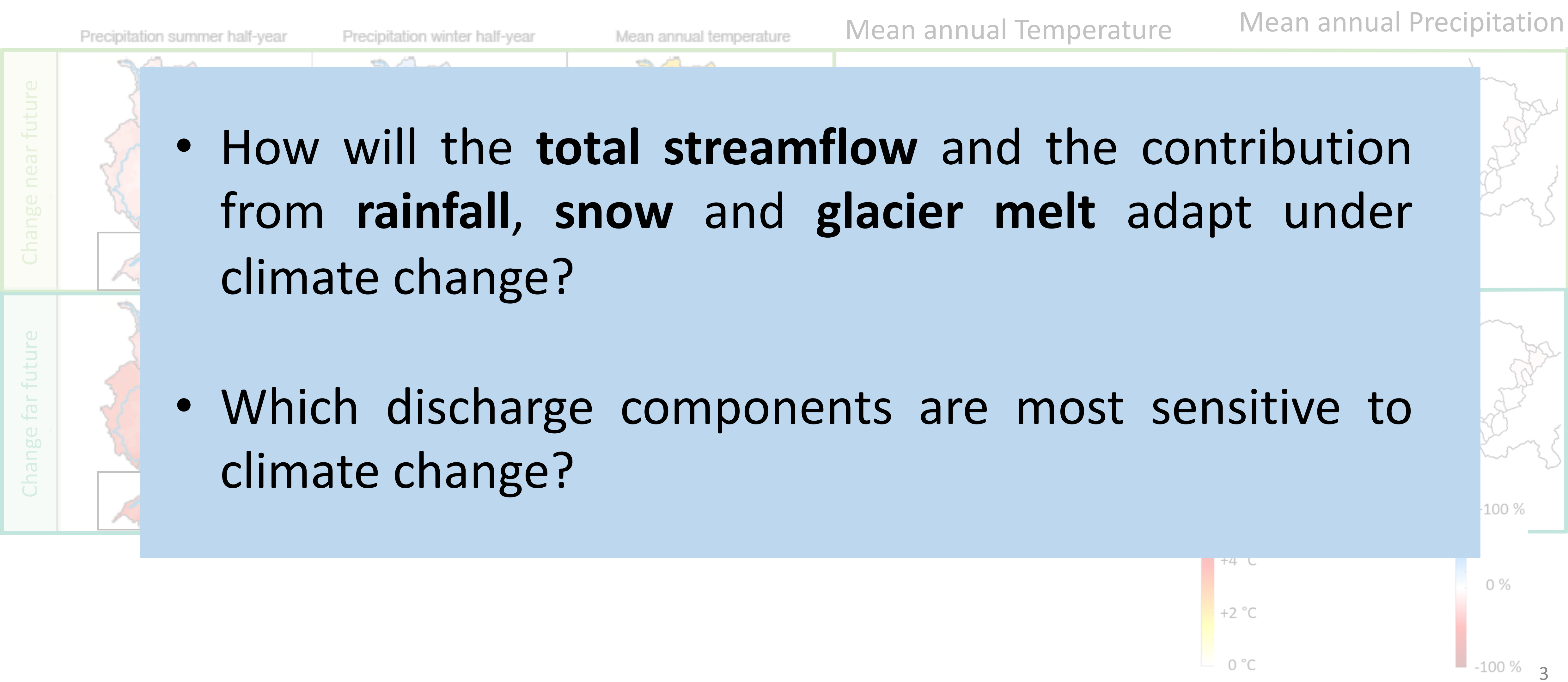


7 member-climate-scenario-ensemble

Reference: 1981 – 2010
Near future: 2031 – 2060
Far future: 2071 - 2100



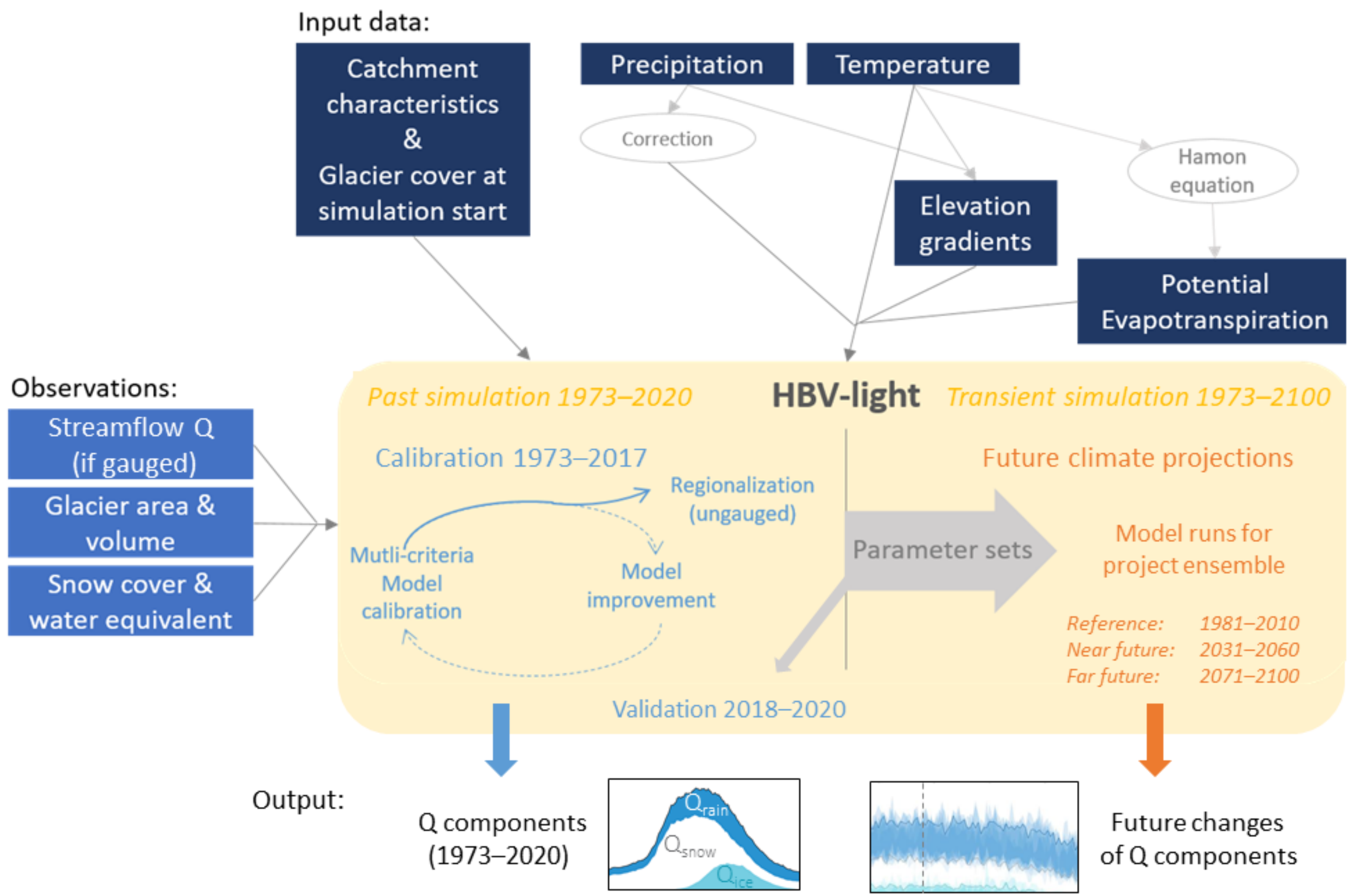
Research questions



- How will the **total streamflow** and the contribution from **rainfall**, **snow** and **glacier melt** adapt under climate change?

- Which discharge components are most sensitive to climate change?

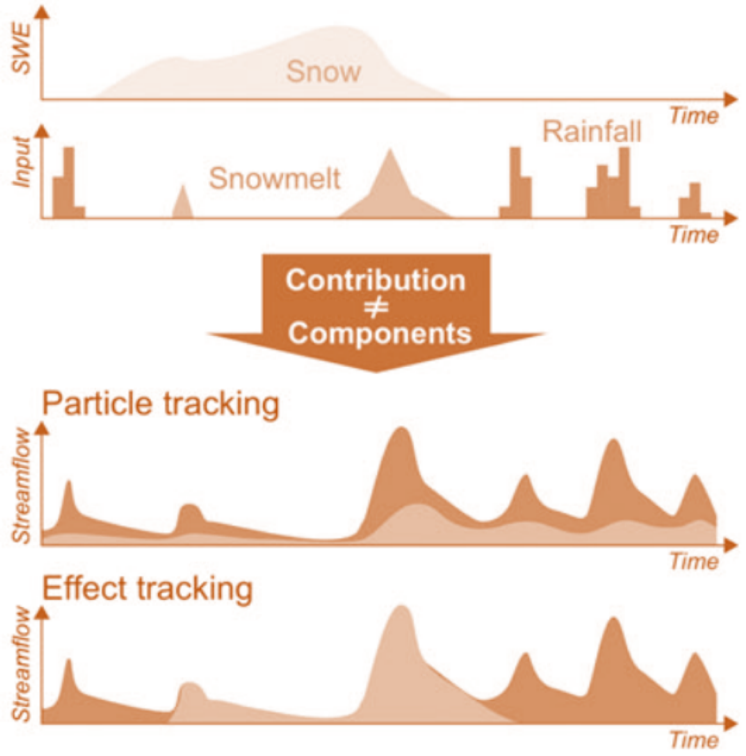
Modelling approach

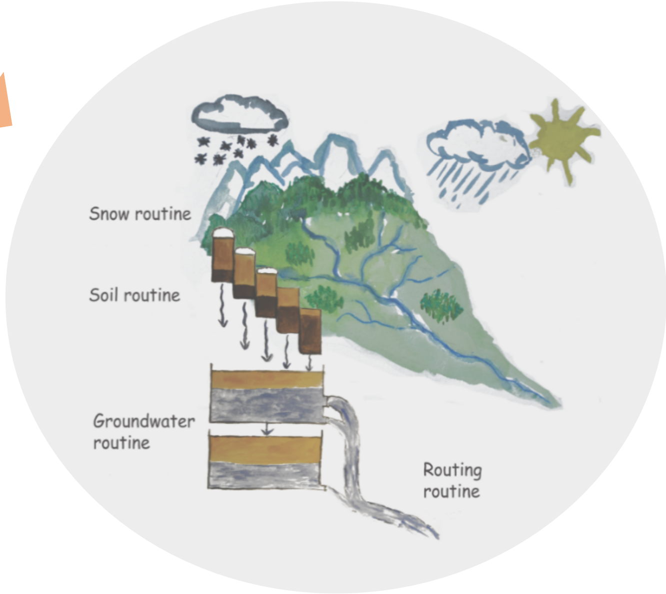


HBV-light bucket type model

Discharge contribution: Effect tracking

Weiler et al. (2018), Hydrological Processes





HBV-light

Seibert and Vis (2012), HESS

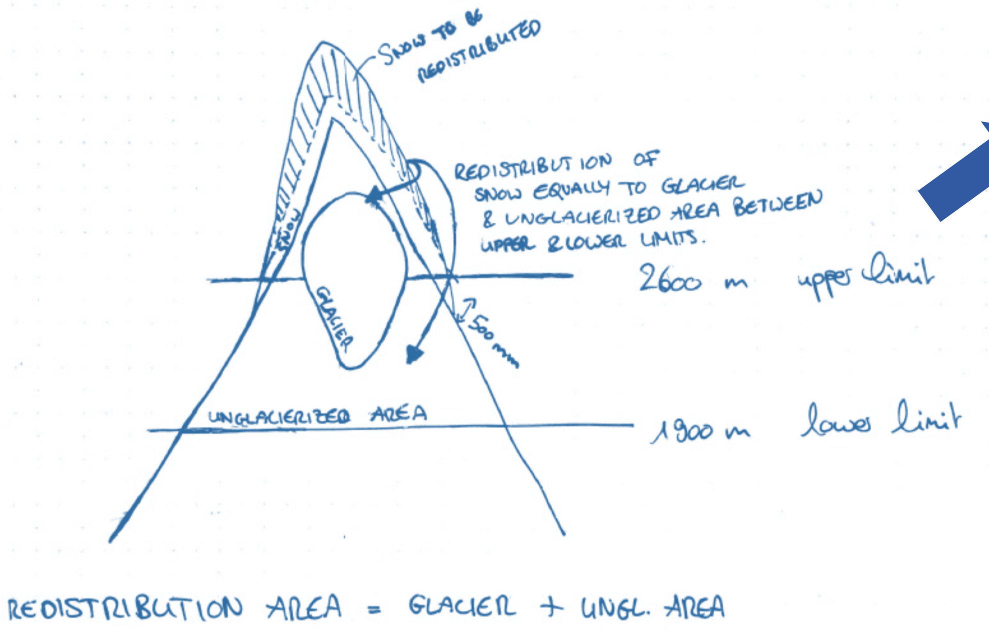
HBV-light bucket type model

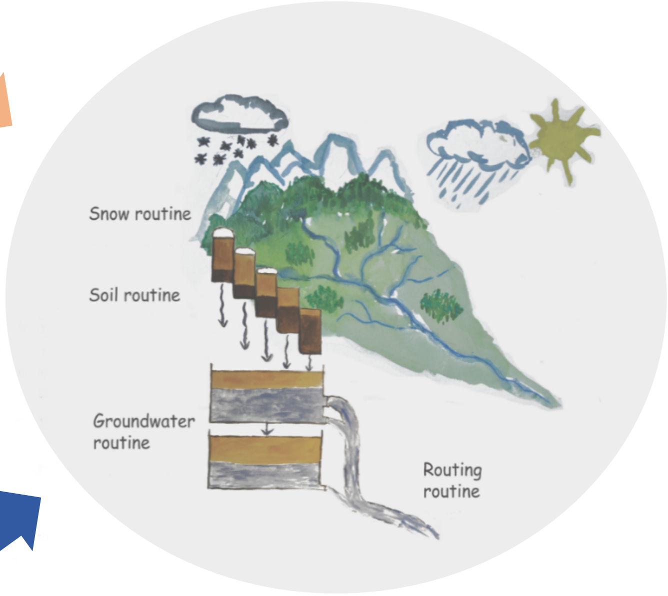
Discharge contribution: Effect tracking

Weiler et al. (2018), Hydrological Processes

Snow Redistribution

Stahl et al (2017), CHR/KHR report
Freudiger et al. (2020), Hydroch-2018 report





HBV-light
Seibert and Vis (2012), HESS

HBV-light bucket-type semi distributed model

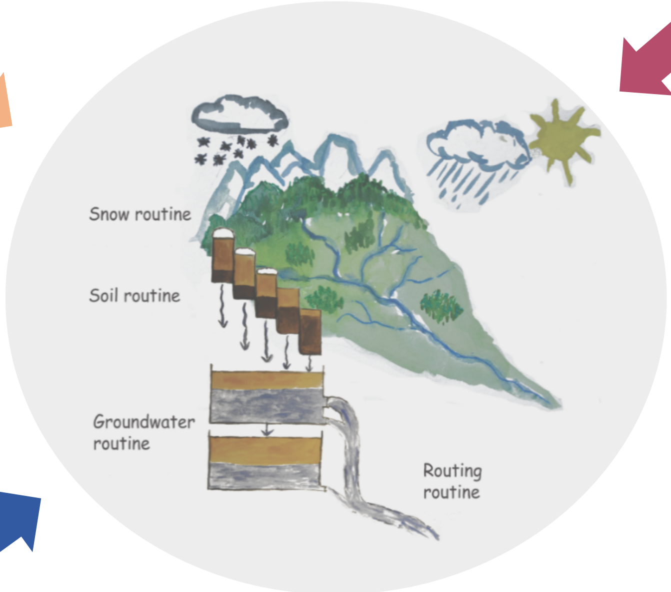
Methods

Discharge contribution: Effect tracking

Weiler et al. (2018), Hydrological Processes

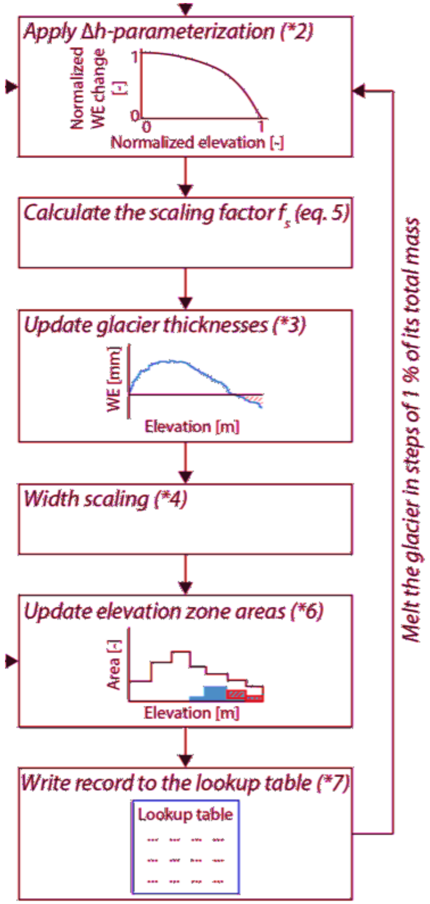
Glacier Geometry transient changes

Seibert et al. (2018), HESS



HBV-light

Seibert and Vis (2012), HESS



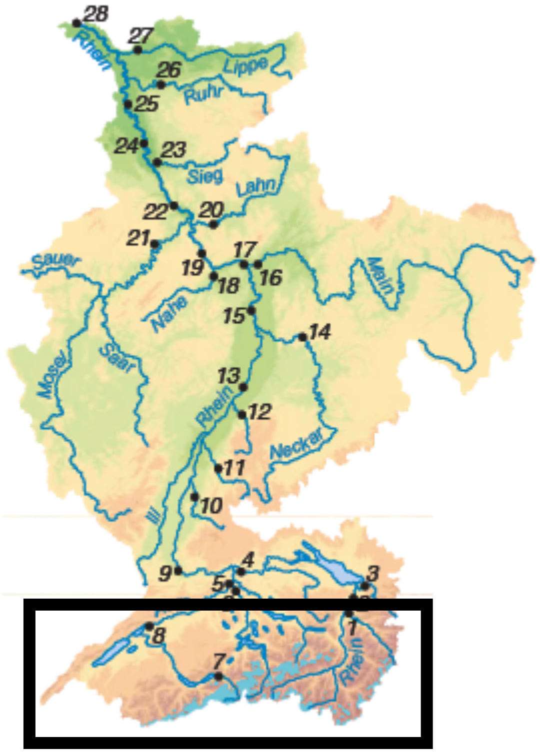
Snow Redistribution

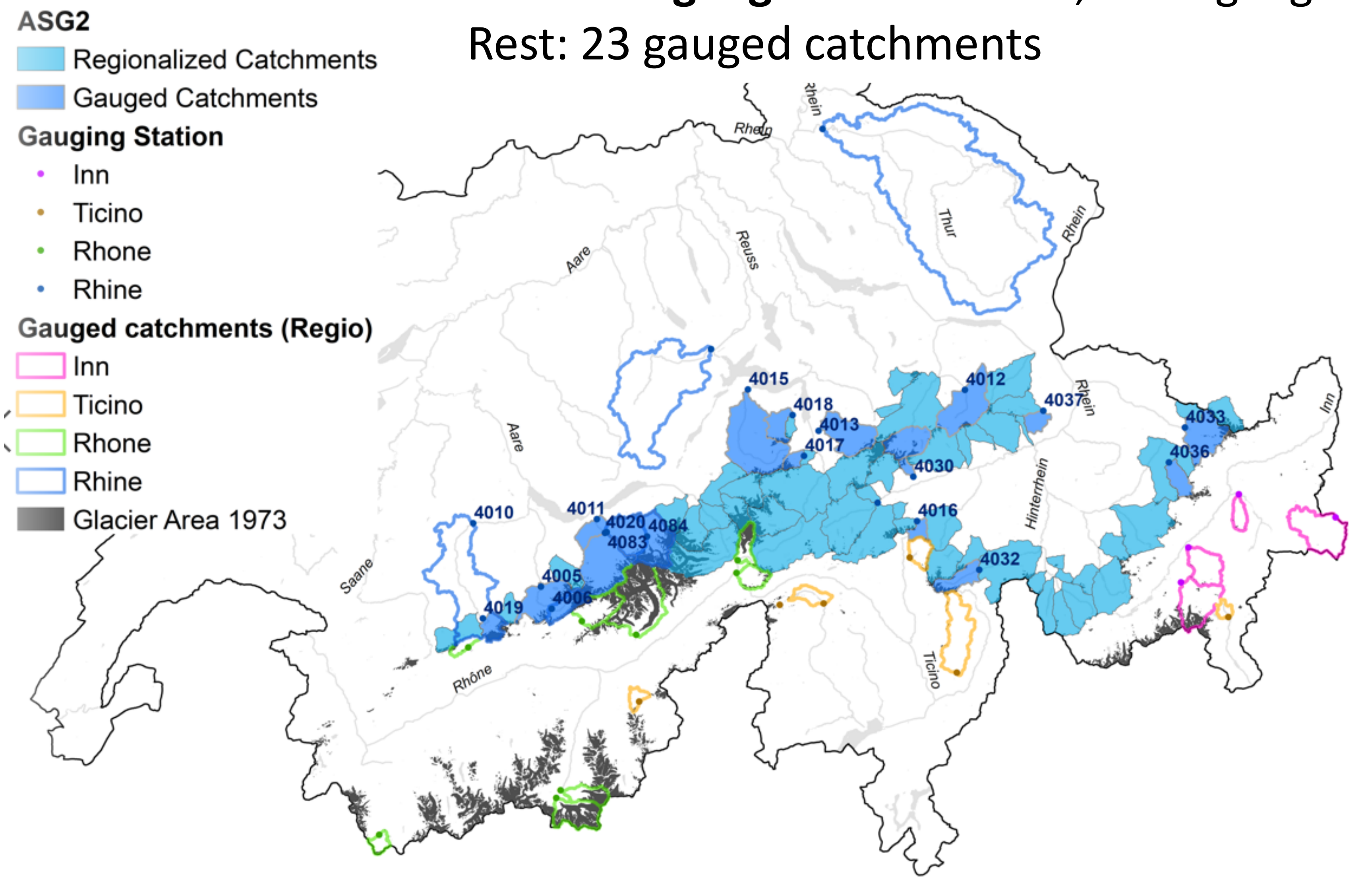
Stahl et al (2017), CHR/KHR report

Freudiger et al. (2020), Hydroch-2018 report

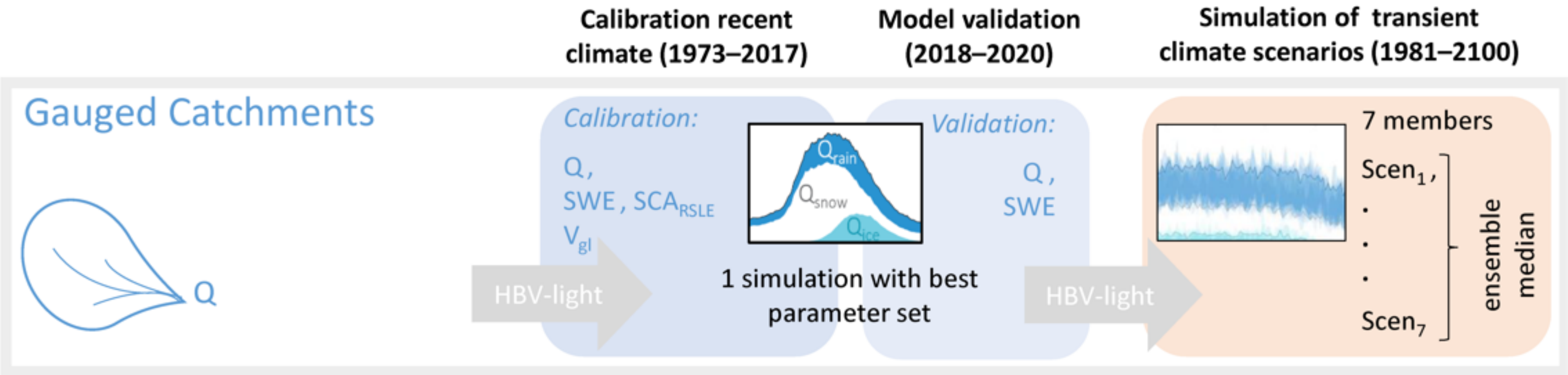
66 glacierized headwater catchments

Rhine: **15 gauged** catchments, 51 ungauged
Rest: 23 gauged catchments





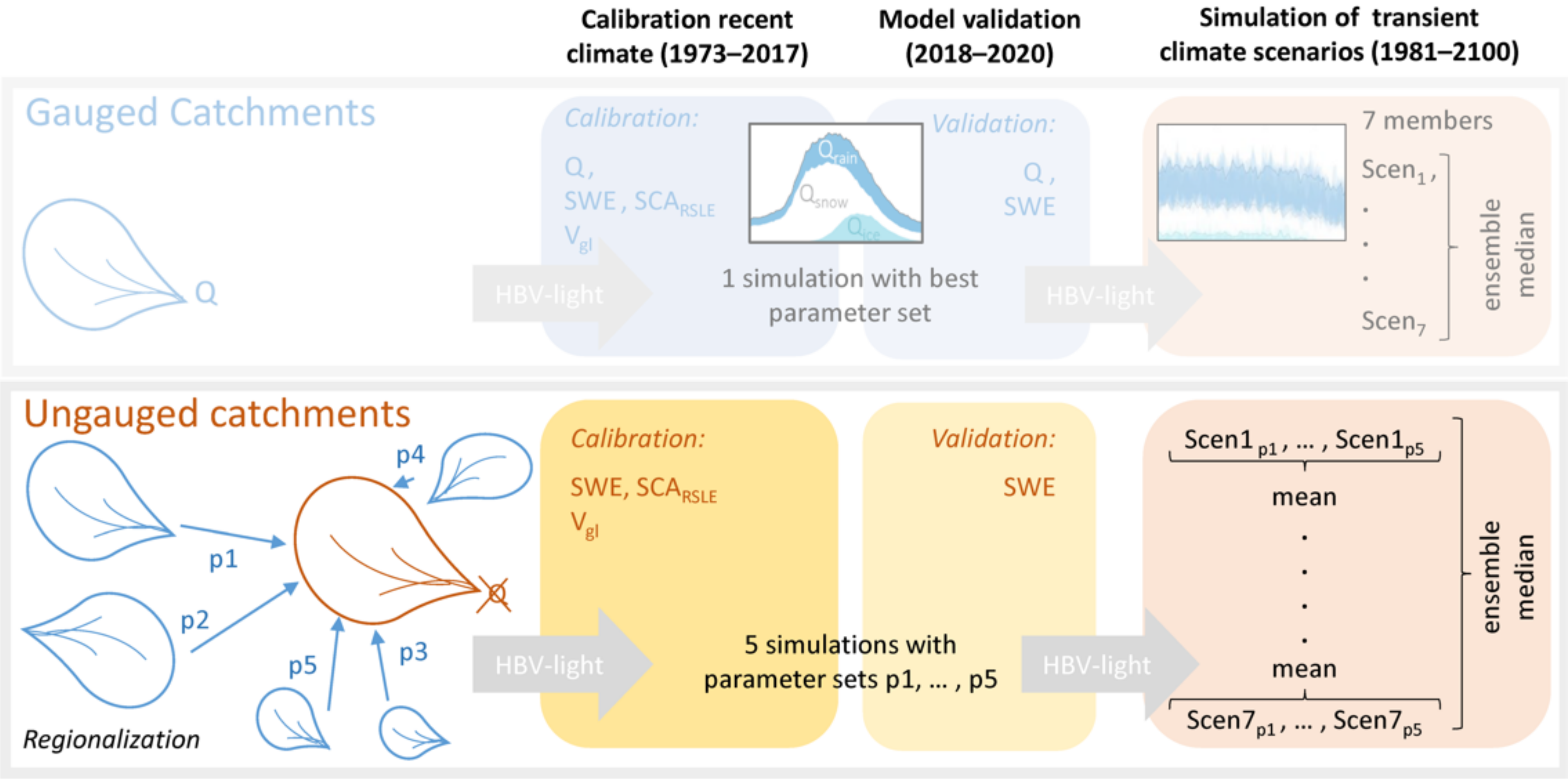
Calibration approach



Multi-criteria calibration on discharge, snow and glacier data

Regionalization approach

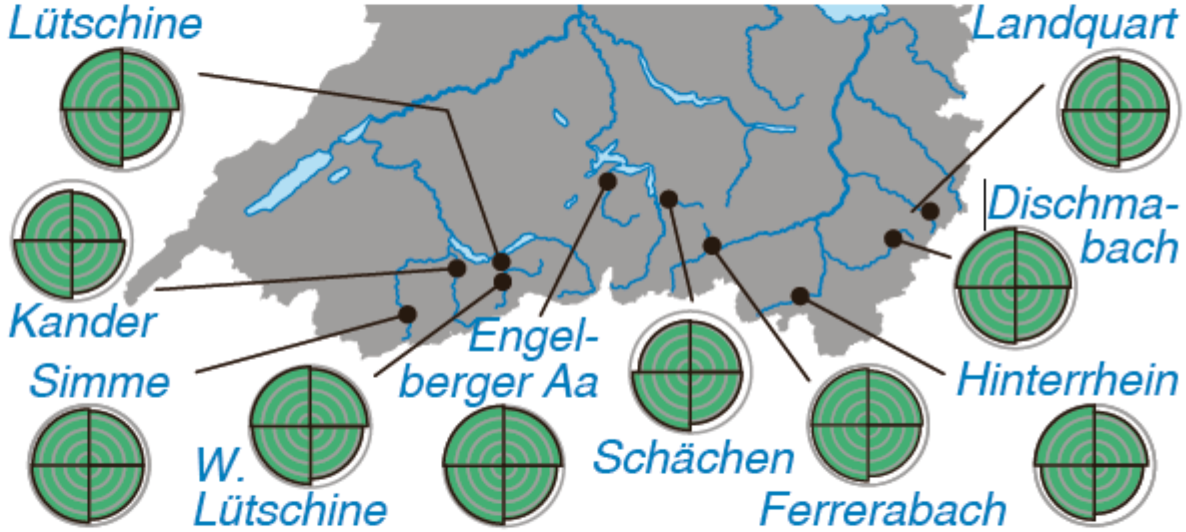
Methods



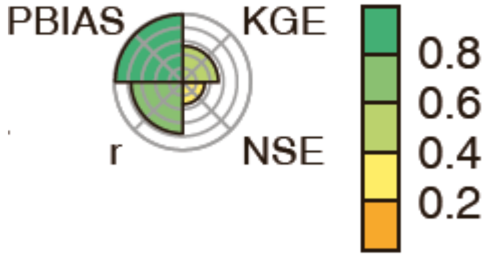
Q: Streamflow, SWE: Snow water equivalent, SCA: Snow covered area derived from regional snow line elevation (RSLE), V_{gl}: Glacier volume

Calibration of gauged catchments

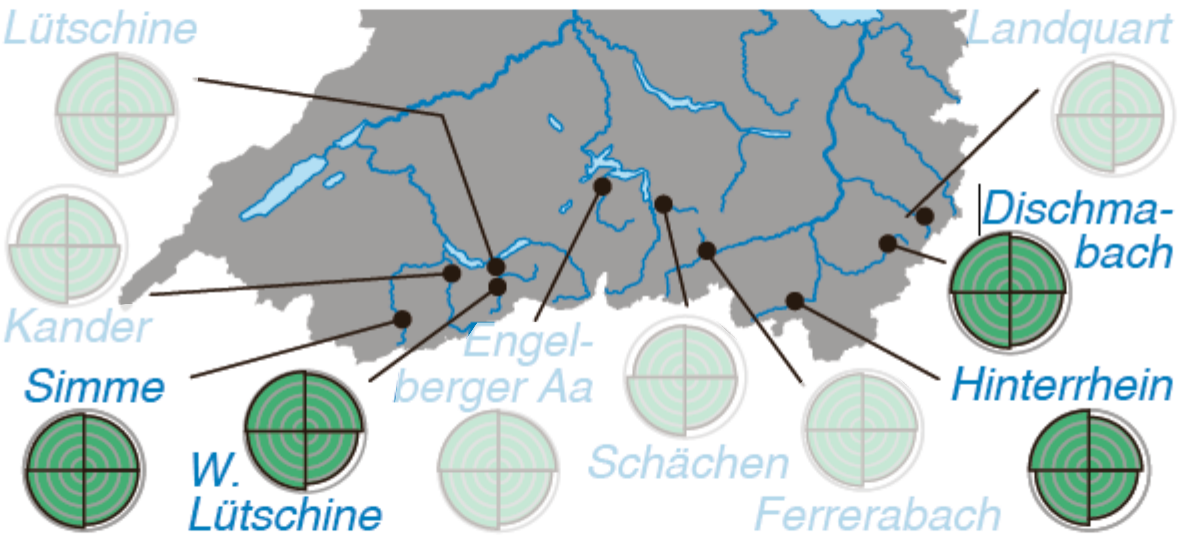
Results

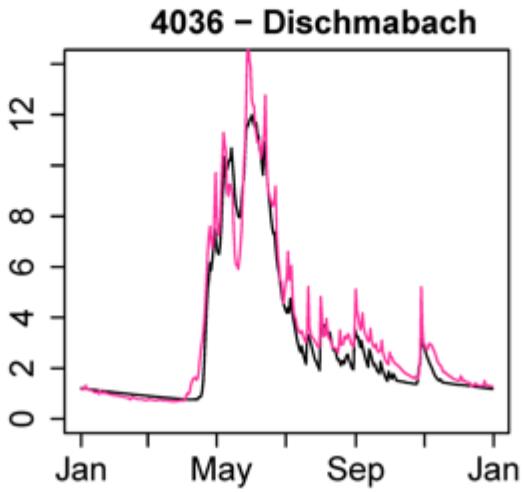


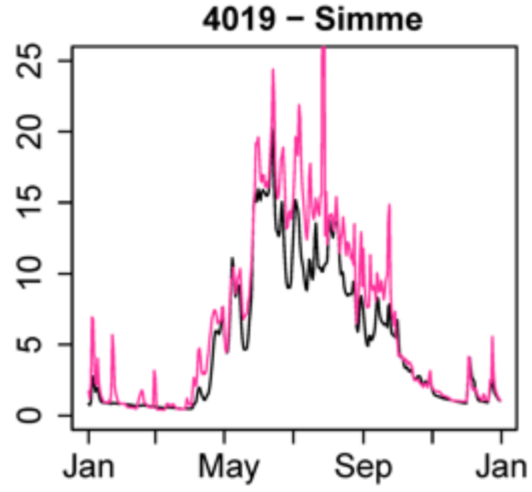
Kling-Gupta-Model efficiency (KGE): for overall performance,
Nash-Sutcliffe efficiency
of the logarithm of streamflow (NSE): for low flow representation,
Correlation coefficient (r): for agreement of relative variations,
Normalized bias measure (PBIAS): for overall deviation.

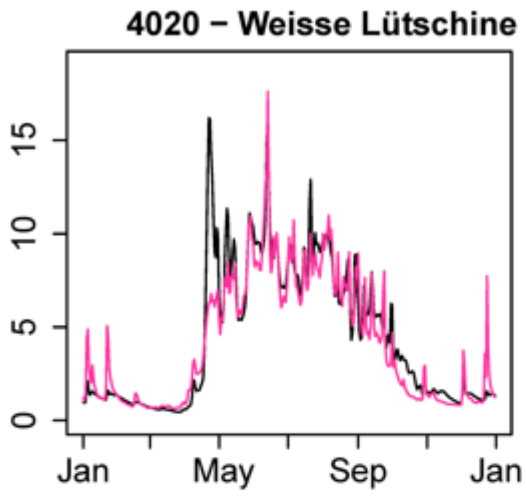


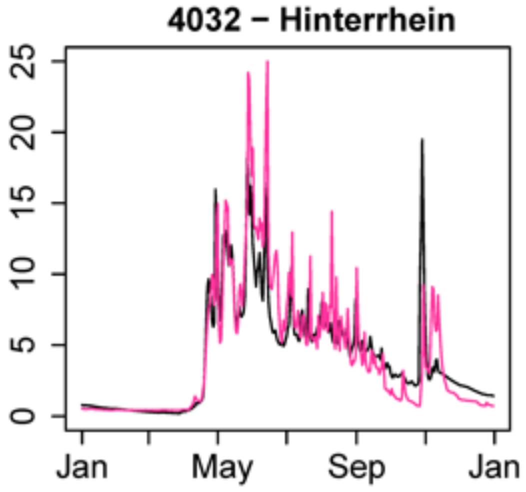
Validation of gauged catchments: Regime 2018 (examples)







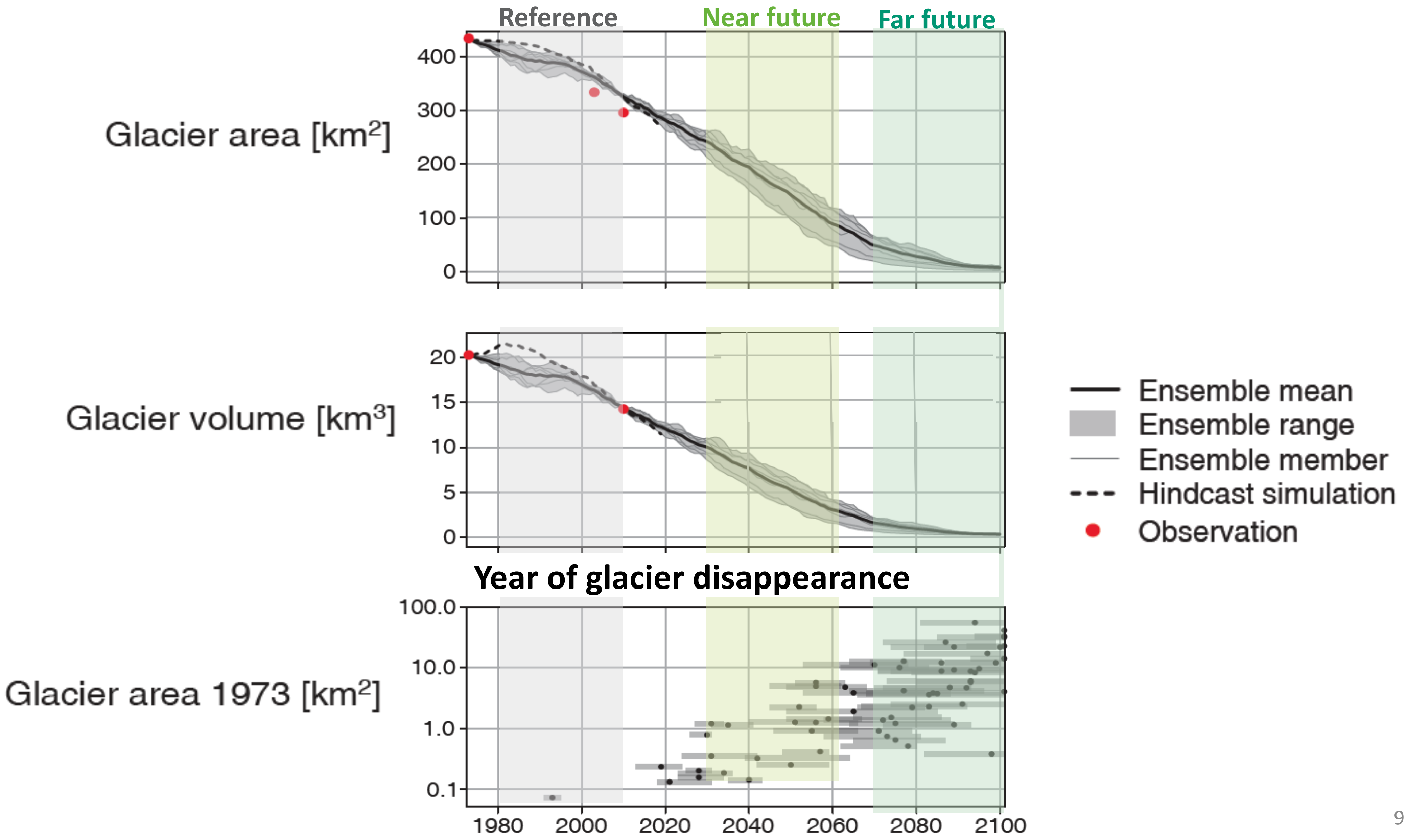




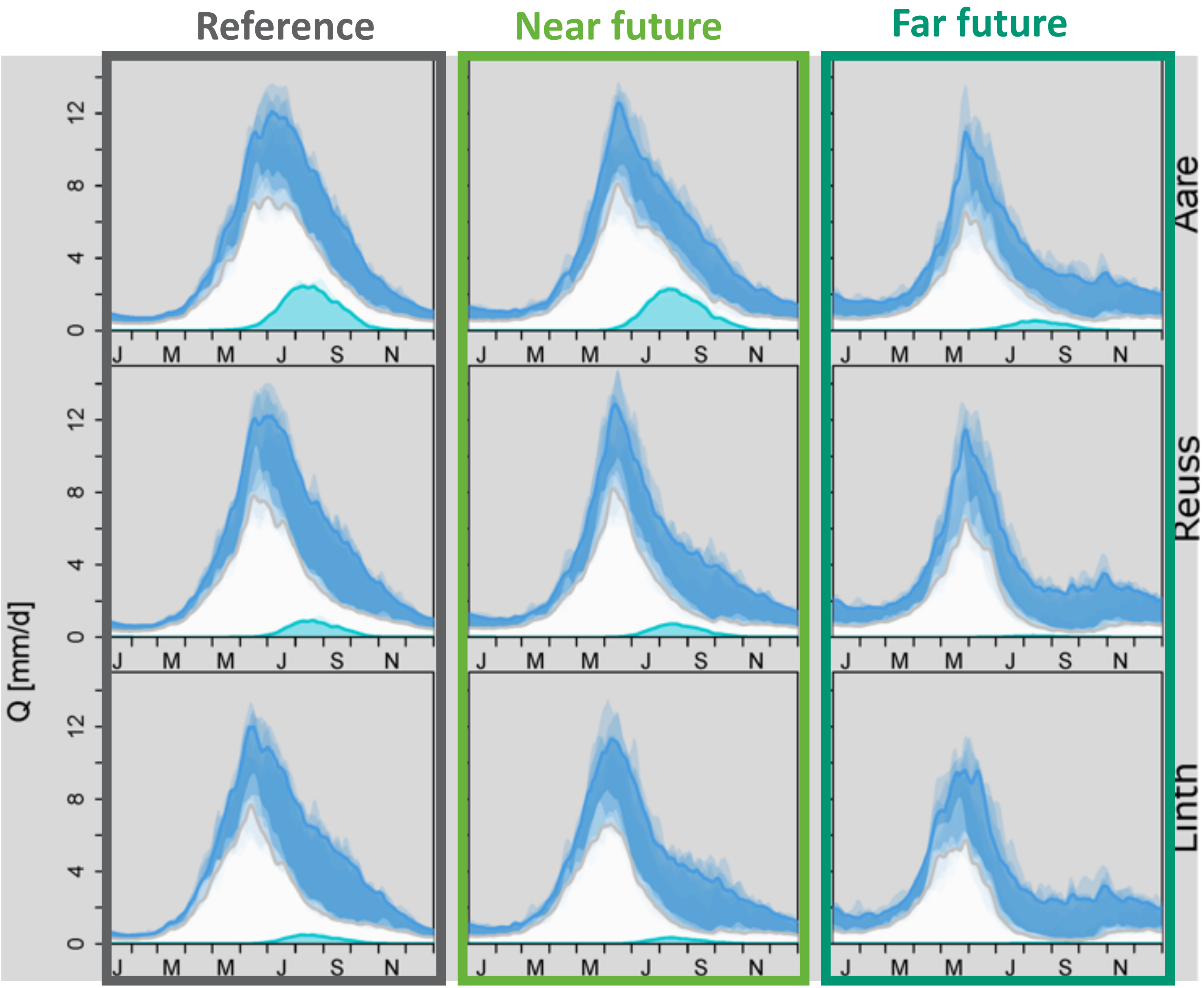
Q_{sim}

Q_{obs}

Projected glacier retreat



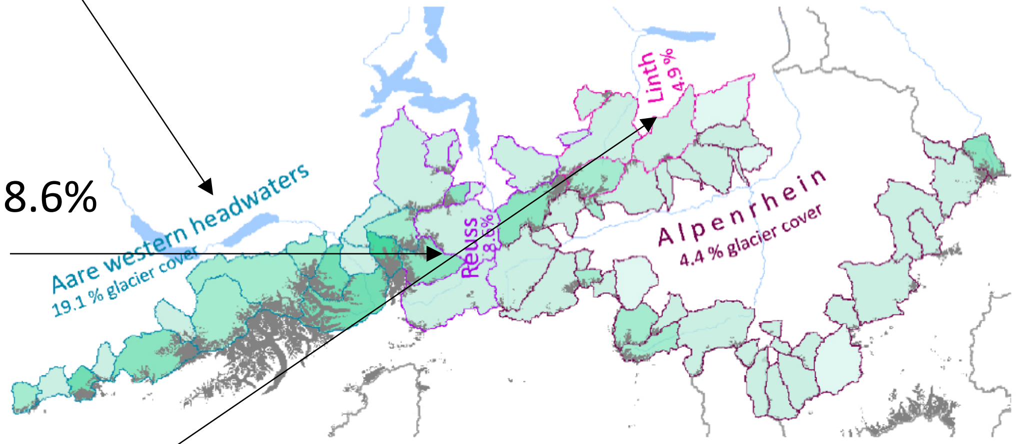
Projected streamflow components (sum of all catchments)



19.1% glacier cover

8.6%

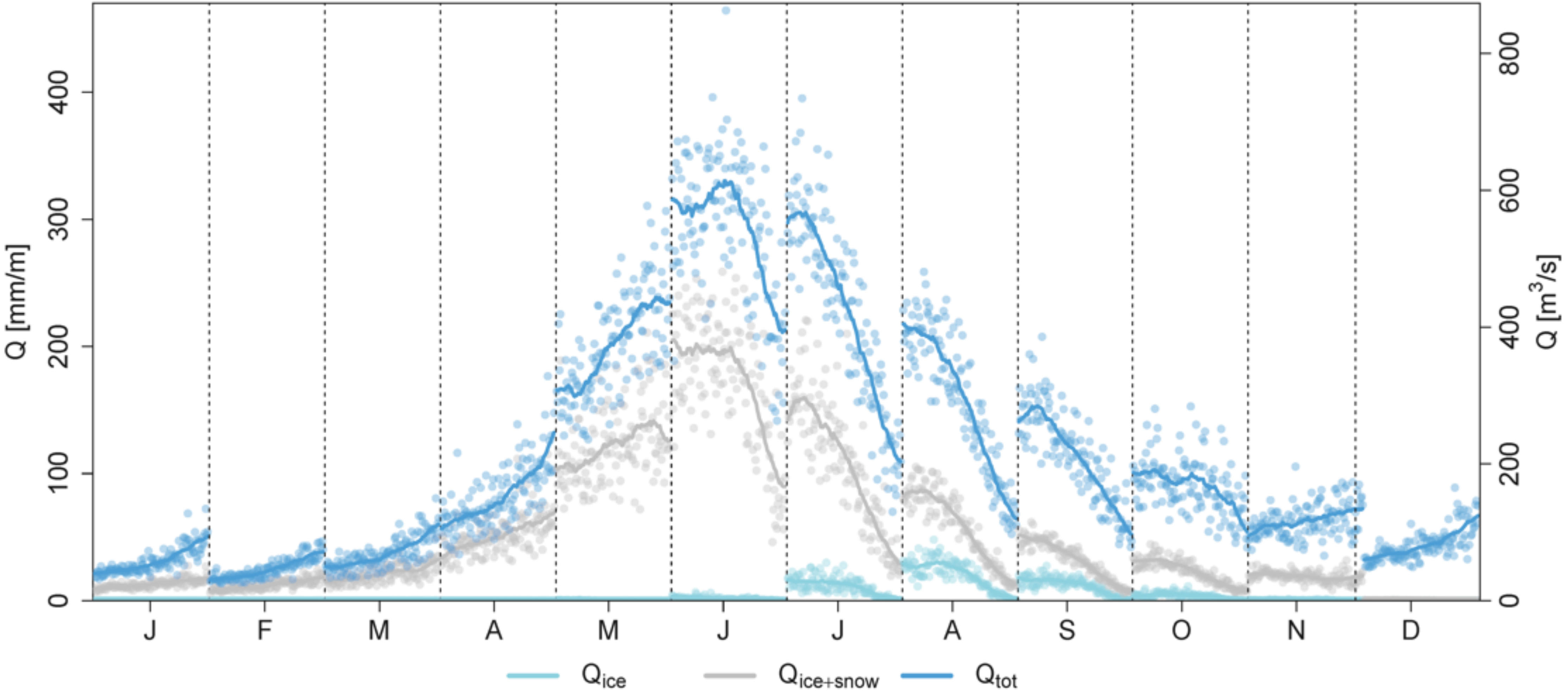
4.9%



Q_{ice} Q_{snow} Q_{rain}

7 member-climate-scenario-ensemble

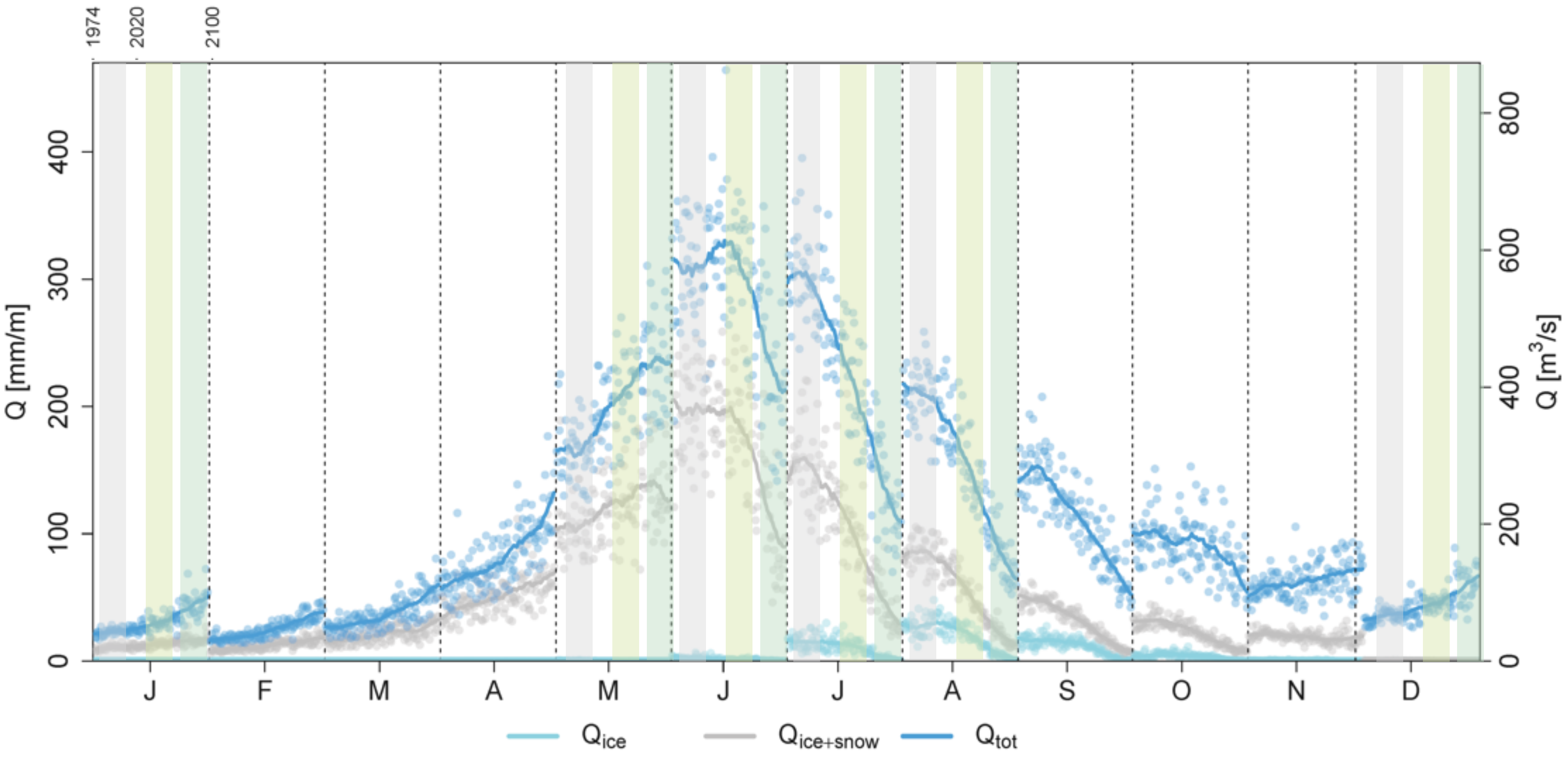
Projected streamflow components (sum of all catchments)



7 member-climate-scenario-ensemble

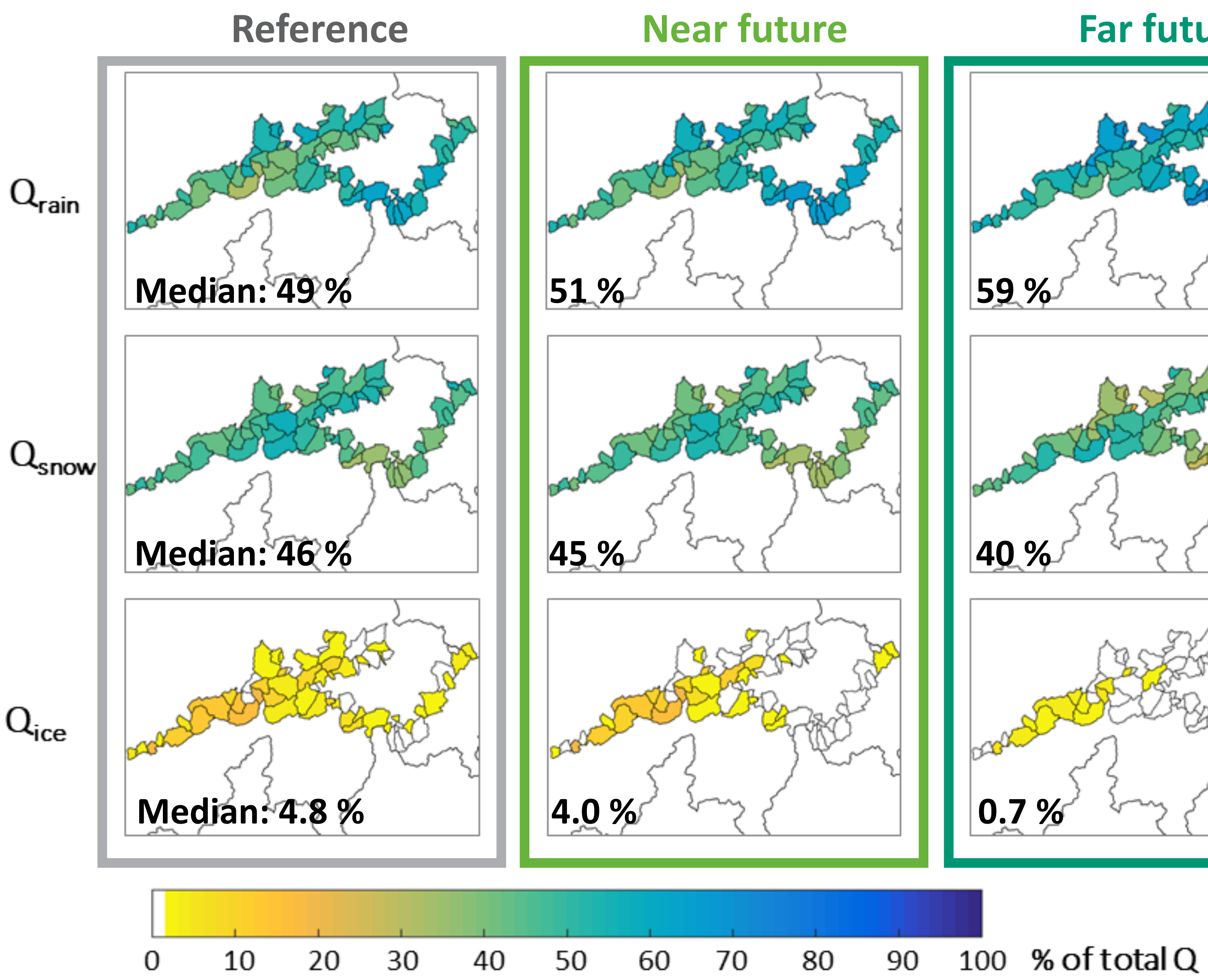
Projected streamflow components (sum of all catchments)

Reference Near future Far future



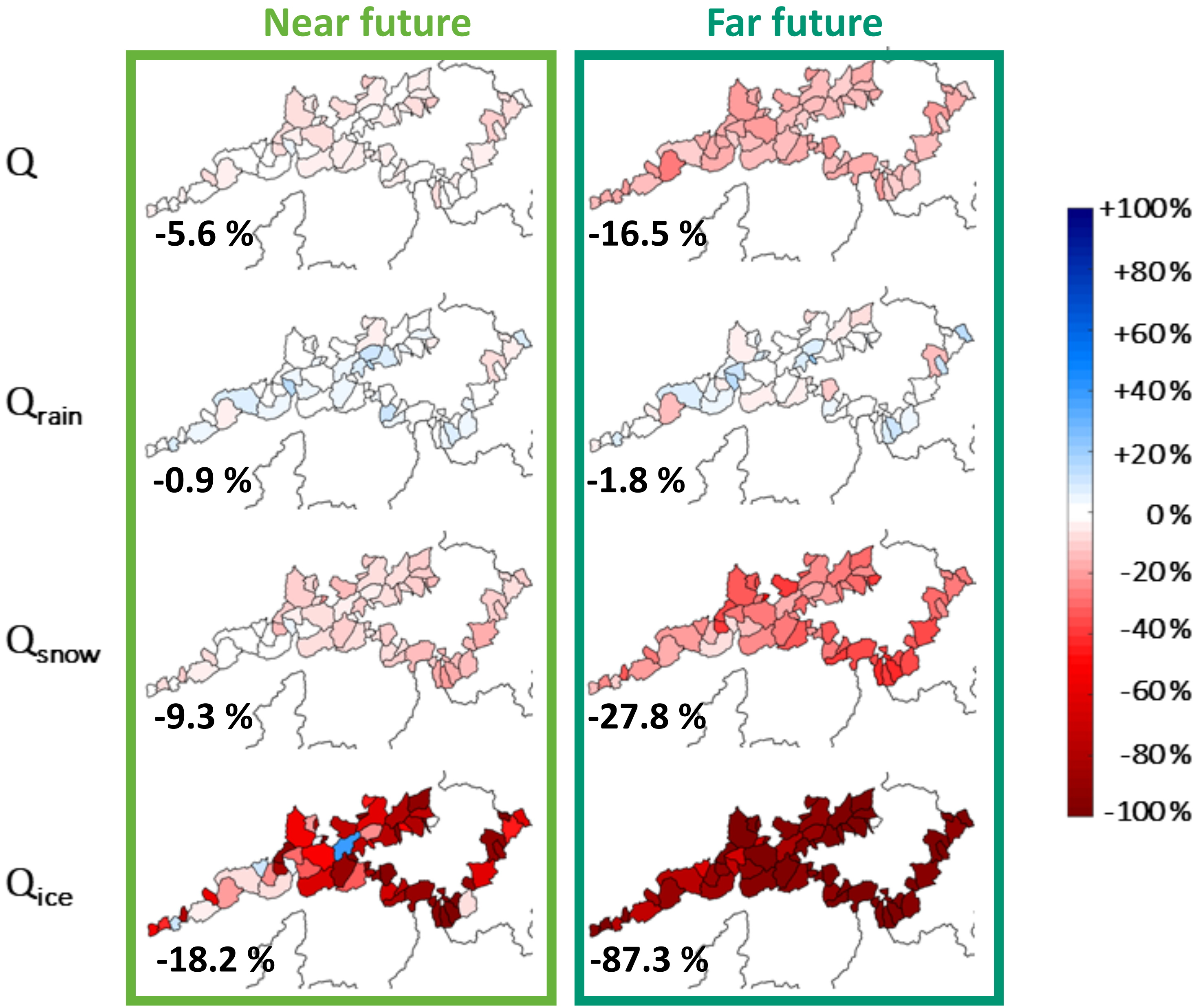
7 member-climate-scenario-ensemble

Projected contribution to Q_{tot} (ensemble median)



Contribution to total streamflow $Q_i/Q_{tot} \cdot 100$

Projected changes of contribution (ensemble median)



Changes compared to reference $Q_{i,rcp}/Q_{i,ref} \cdot 100$

Conclusions & outlooks

- Total streamflow (based on 7 member-climate-scenario-ensemble for RCP 8.5) is expected to decrease by up to 16.6% in far future in the headwater catchments.
- Q_{Rain}, Q_{Snow} and Q_{Ice} will experience large changes that differ spatially. These differences can mostly be explained by glacier cover and mean catchment elevation.
- While Q_{Rain} will only slightly decrease, Q_{Snow} and Q_{Ice} will experience large decreases, with some glaciers remaining in only 25% of the catchments at the end of the 21st century.
- The changes in Q_{Rain}, Q_{Snow} and Q_{Ice} will lead to a shift of the seasonality of Q_{tot} with earlier discharge peaks due to earlier snowmelt events and smaller peaks due to negative changes in Q_{Snow} and Q_{Ice}
- These substantial changes have to be considered for future water availability and successful adaptation and mitigation measures

Thank you very much
For your attention

Thanks to:
FOEN, Cantons Bern, Ticino, St. Gallen and Glarus, AlpiQ, OFIMA, H. Huwald, M. Huss, N. Griessinger, T. Jonas and S. Fugger for providing us with data for model calibration