Overview about the impact of snow cover images on the improvement of hydrological modelling

COST Action: ES1404, Remote Sensing Products of Cryosphere using Sentinels, WG3

ZAMG, Vienna, Austria

18 April 2016

HÁSKÓLINN Í REYKJAVÍK
REYKJAVIK UNIVERSITY

Veðurstofa Íslands

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Hydropower in Europe

Annual Hydropower Production:

EU:	~397.7 TWh
Norway:	~122.1 TWh
Austria:	~43.4 TWh
Switzerland:	~35.3 TWh
Iceland:	~12.3 TWh

(Pot: 220 TWh/yr → 0.7 GWh/pers)

(Data: UN Energy Stat.; NEA, 2014)

Motivation

mbl.is

fimmtudagur, 24. apríl 2014

Forsíða Viðskipti Íþróttir Fólkið Smartland Monitor Bílar Greinar

Innlent Erlent Tækni og vísindi Kosningar Nýjast Vinsælast Fréttaleit News in English

Innlent | Morgunblaðið | 15.4.2014 | 5:30

Hækkar lítillega í miðlunarlónum

Staðan á miðlunarlónum Landsvirkjunar fer batnandi. Tímabundið aukið rennsli í

hægt sé að aflétta skerðingum til stórnotenda, að því er fram kemur í Morgunblaðinu í dag.

Tíðarfarið í vetur hefur verið Landsvirkjun mjög óhagstætt og innrennsli í lónin afbrigðilegt. En breyting varð til batnaðar í veðrinu í byrjun apríl og í síðustu viku hófst hægfara leysing á hálendinu og rennsli í Tungnaá, Þjórsá og Blöndu jókst.

Blöndulón á Auðkúluheiði. mbl.is/Einar Falur Ingólfsson

Objective: Estimate seasonal contribution of snow, glacier and rainfall runoff in mountain streams

Motivation

Underwater cable connecting Iceland to Europe will come sooner than later

FORSÍÐA | FRÉTTIR | ÍÞRÓTTIR | EYJAN | BLEIKT | KAFFISTOFAN

Fréttasarpur | Fréttatenglar | Viðskipti | Pennar | Orðið | Silfrið | Baksíðan | Veður

Viðskipti Þriðjudagur 20.05.2014 - 18:56 - Ummæli (12)

Sæstrengur verður lagður til Íslands fyrr fremur en síðar

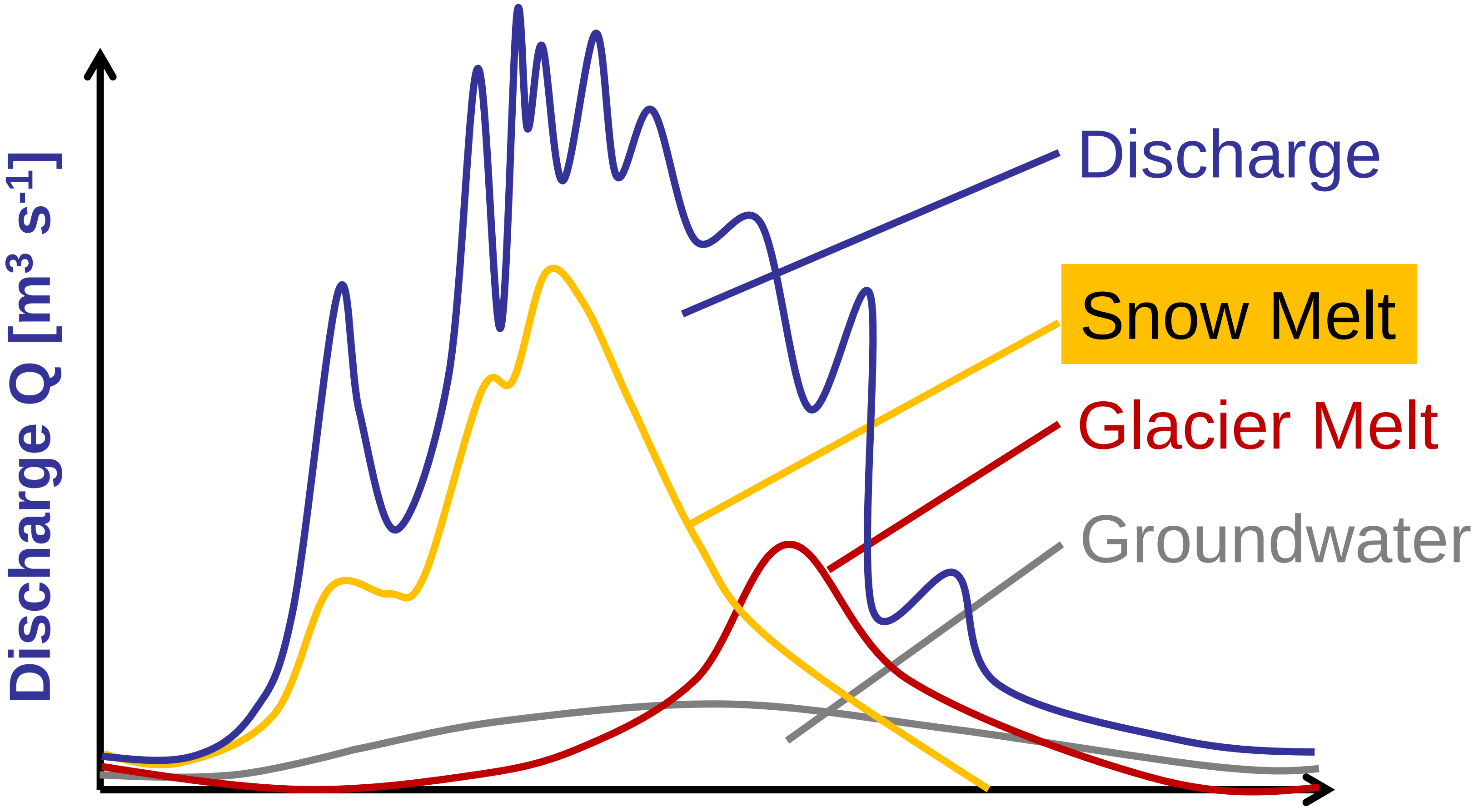
Bjarni Benediktsson, fjármála- og efnahagsráðherra, og Jónas Þór Guðmundsson, stjórnarformaður Landsvirkjunar, helguðu báðir stórum hlutum ræða sinna á ársfundi fyrirtækisins í dag hugmyndum um byggingu sæstrengs til Bretlands. Þeir sammæltust um að um góðan kost gæti verið að ræða, þrátt fyrir að enn sé þörf á að skoða ýmsar hliðar málsins betur. Þá sagði Hörður Arnarsson, forstjóri Landsvirkjunar, að sá tímapunktur muni koma að sæstrengur verði lagður til Evrópu, og að strengur yrði einnig lagður til Bandaríkjanna fyrr fremur en síðar.

Jónas sagði Landsvirkjun mikilvægt að auka fjölbreytni í hópi viðskiptavina, en markvisst hafi verið unnið að því markmiði um nokkurra ára skeið. Erlend fyrirtæki sjái Ísland sem álitlegan kost fyrir

FRÉTTIR

Flugmenn hafa undirritað nýjan kjarasamning

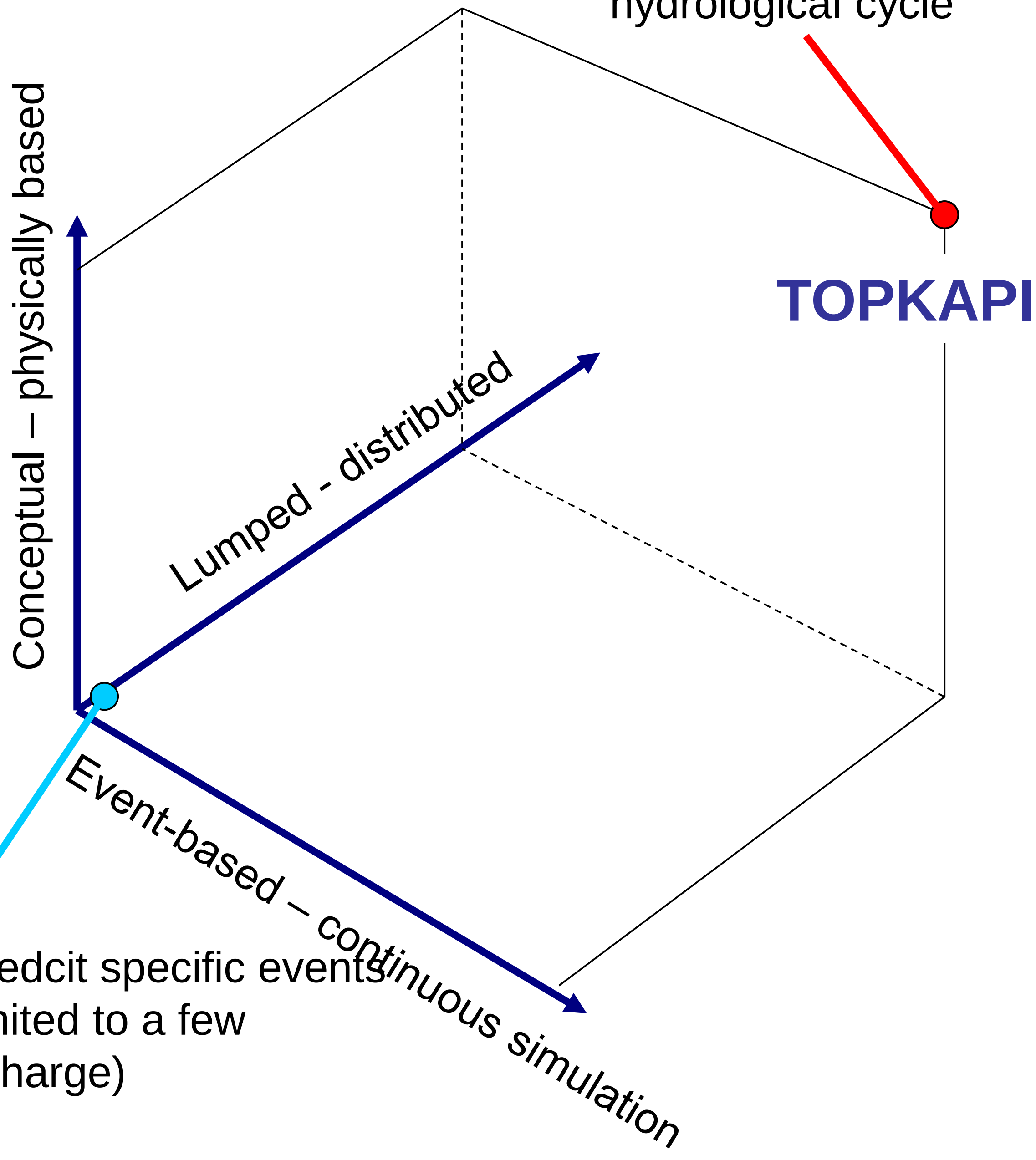
Objective: How much Snow- Glacier and Rain Runoff is available for Hydropower Production



Finger (2013)

Model Complexity

Complex models: which can compute noumerous variables related to the hydrological cycle



Simple Models: predcit specific events and are usually limited to a few variabes (e.g. discharge)

TOPKAPI

1. Clear sky irradiance

$$I_{csG\downarrow i} = f(\theta_s, \delta, Tr, \nabla_{slope}, A_{cell}, lat)$$

2. Cloud factor

$$cf_{j(i)} = c_1 + c_2 \cdot \Delta T_{j(i)}$$

3. Albedo

$$\alpha_{snow(i)} = Alb_{f1} - Alb_{f2} \cdot \log_{10}\left(T_{acc(i)}\right)$$

4. Snow and Ice melt

$$M_i = TF \cdot T_i + SRF \cdot I_{G\downarrow i} \cdot \left(1 - \alpha_i\right)$$

5. Snow and Ice reservoir

$$Q_t = Q_{t-1} \cdot \exp\left(-\frac{1}{k}\right) + \left(1 - \exp\left(-\frac{1}{k}\right)\right) \cdot V_{New(t)}$$

6. 2 Soil layers

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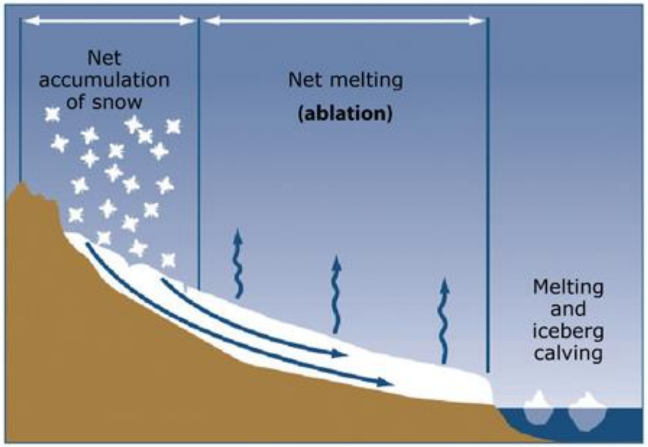
Multi-Variable calibration according to Finger et al. 2011

Discharge **(Q)**
- 10 min resolution
- Rhone valley

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Q_{i,\mathrm{obs}} - Q_{i,\mathrm{sim}}\right)^2}{\sum_{i=1}^{n}\left(Q_{i,\mathrm{obs}} - \overline{Q_{i,\mathrm{obs}}}\right)^2}$$



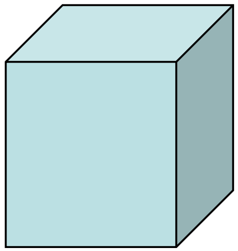
Mass Balances **(MB)**
- Every 100 m altitude
- 1900 to present
- → For Gletsch: 2 values per year
- (winter and summer)

$$RMSE_{MB} = \sqrt{\sum_{j=1}^{m}\left(MB_{j,\mathrm{obs}} - MB_{j,\mathrm{sim}}\right)^2}$$

MODIS snow cover data **(SC)**
- Twice a day (TERRA and AQUA)
- 500 m resolution
- Entire world

$$CPSC = \frac{c_{\mathrm{corr}}}{c_{\mathrm{tot}} - c_{\mathrm{missing}}}$$

Stochastic Calibration: Monte Carlo Simulations (Finger et al., 2011)



1. Run 10’000 plausible parameter sets

2. Assessment of performance

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Q_{i,\mathrm{obs}} - Q_{i,\mathrm{sim}}\right)^2}{\sum_{i=1}^{n}\left(Q_{i,\mathrm{obs}} - \overline{Q_{i,\mathrm{obs}}}\right)^2}$$

$$RMSE_{MB} = \sqrt{\sum_{j=1}^{m}\left(MB_{j,\mathrm{obs}} - MB_{j,\mathrm{sim}}\right)^2}$$

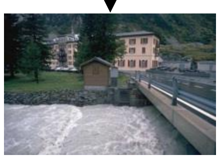
$$CPSC = \frac{c_{\mathrm{corr}}}{c_{\mathrm{tot}} - c_{\mathrm{missing}}}$$

3. Ranking of parameter sets according to the 3 criteria

$$P_r^i = \frac{(N+1) - Rank_r^i}{N}$$

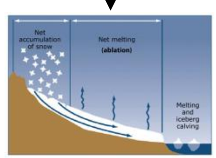
4. Determination of the ranking value

5. Overall performance = average of P^i_r



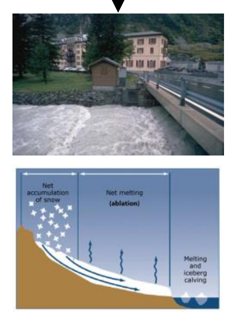
Q

SC

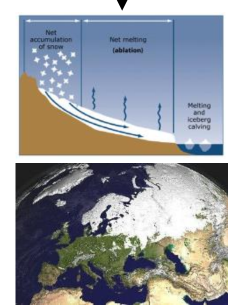


MB

Q + SC



Q + MB

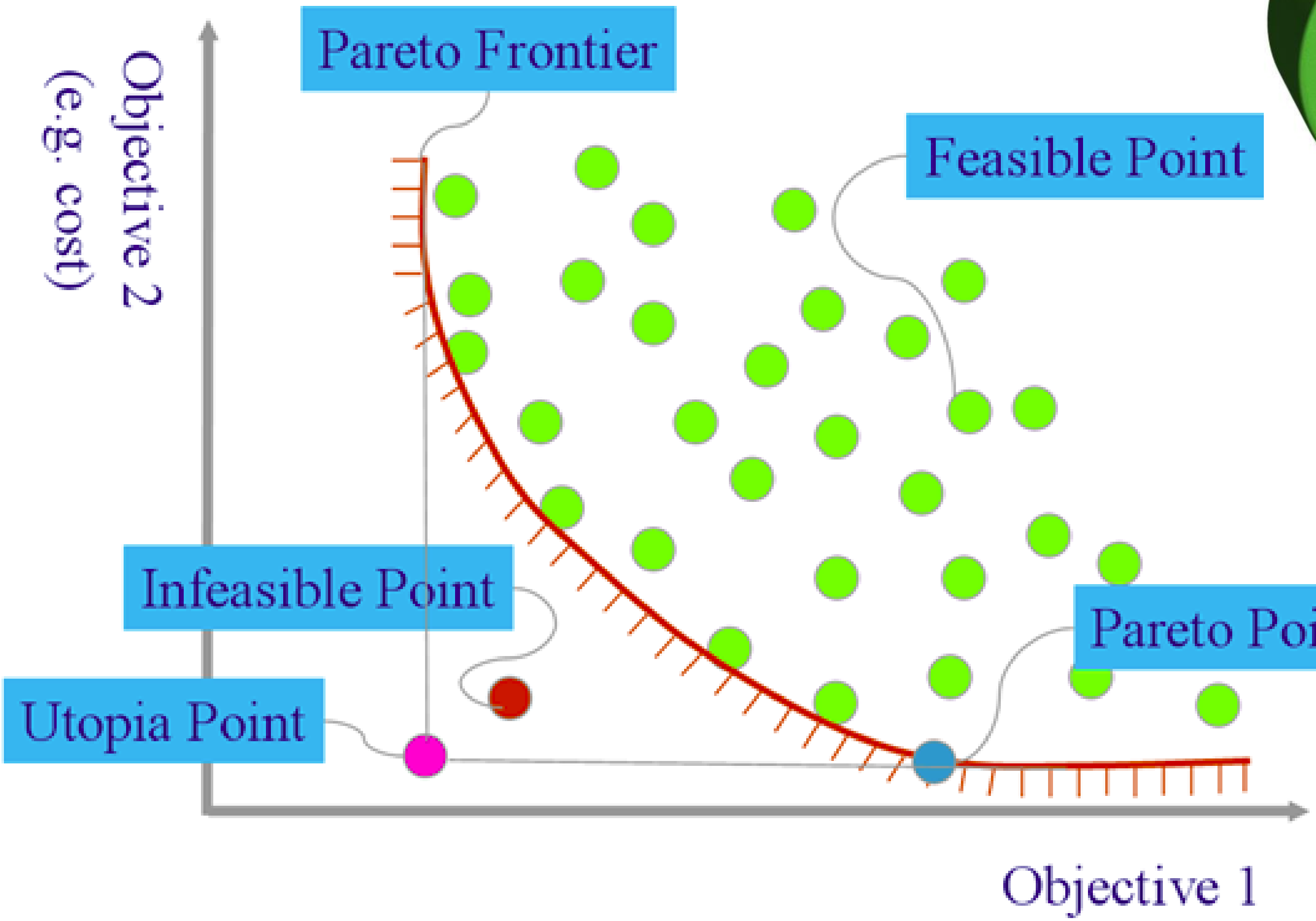


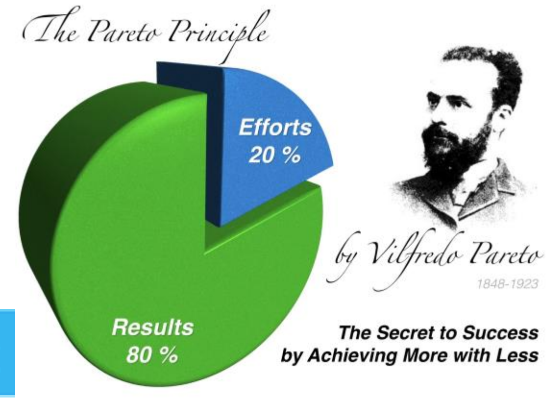
MB + SC

Q + MB + SC

Finger et al. (2011)

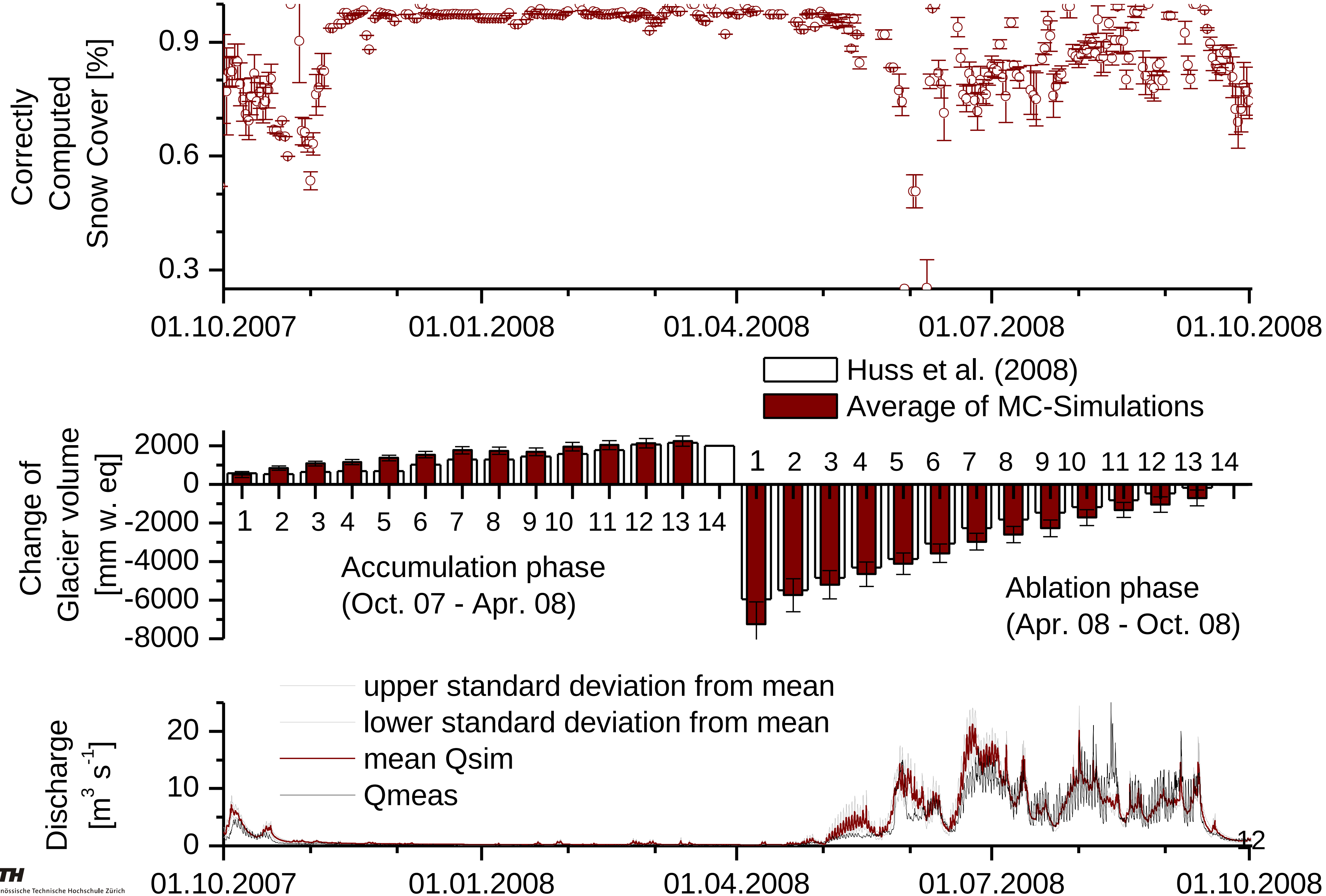
Multiple dataset calibration: Pareto Frontier





- 80% of the effects come from 20% of the causes.
- 80% of the land in Italy was owned by 20% of the population
- 20% of the peapods in his garden contained 80% of the peas

Results of snow cover, mass balances and discharge of the 100 best MC runs



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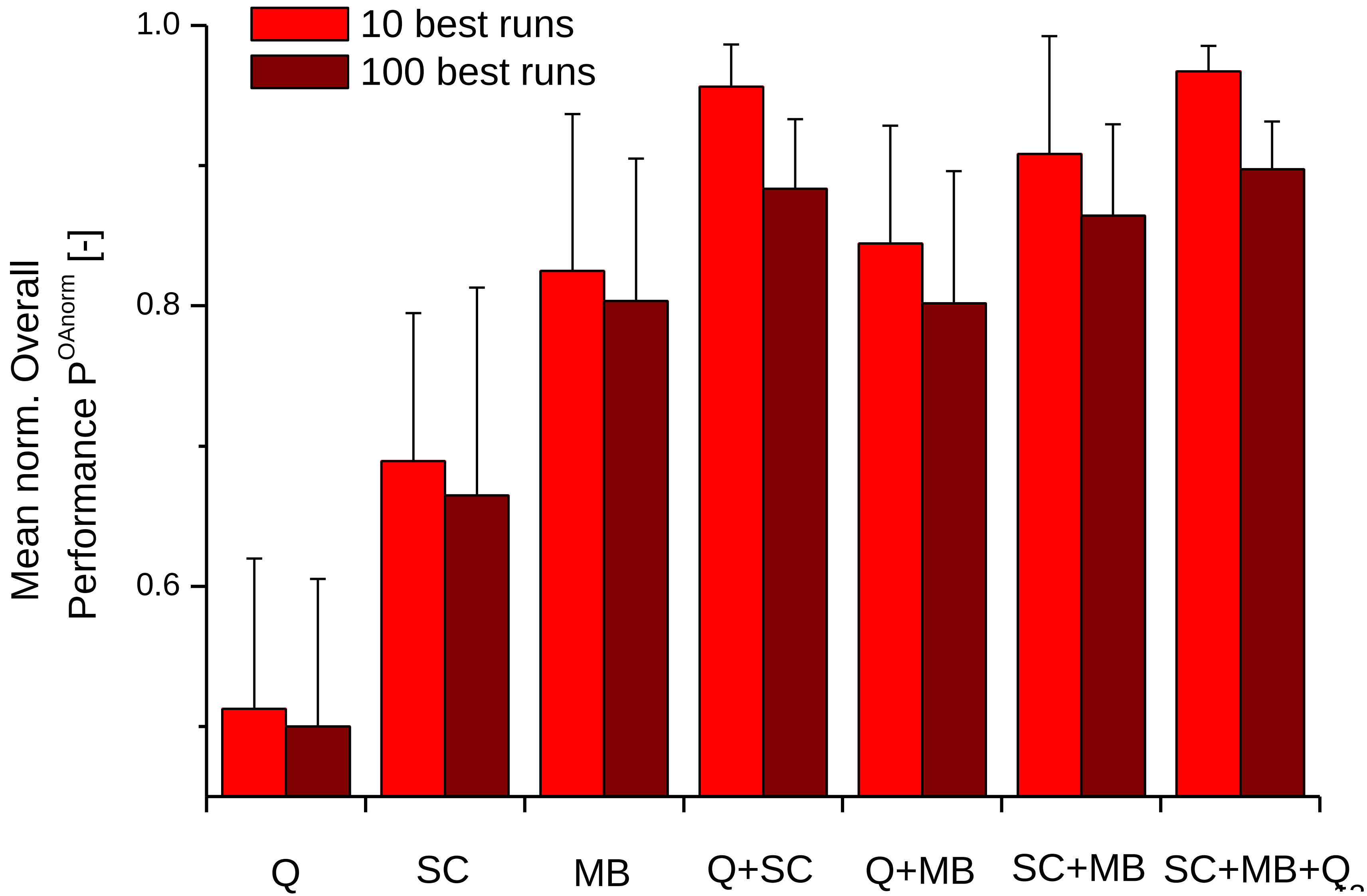
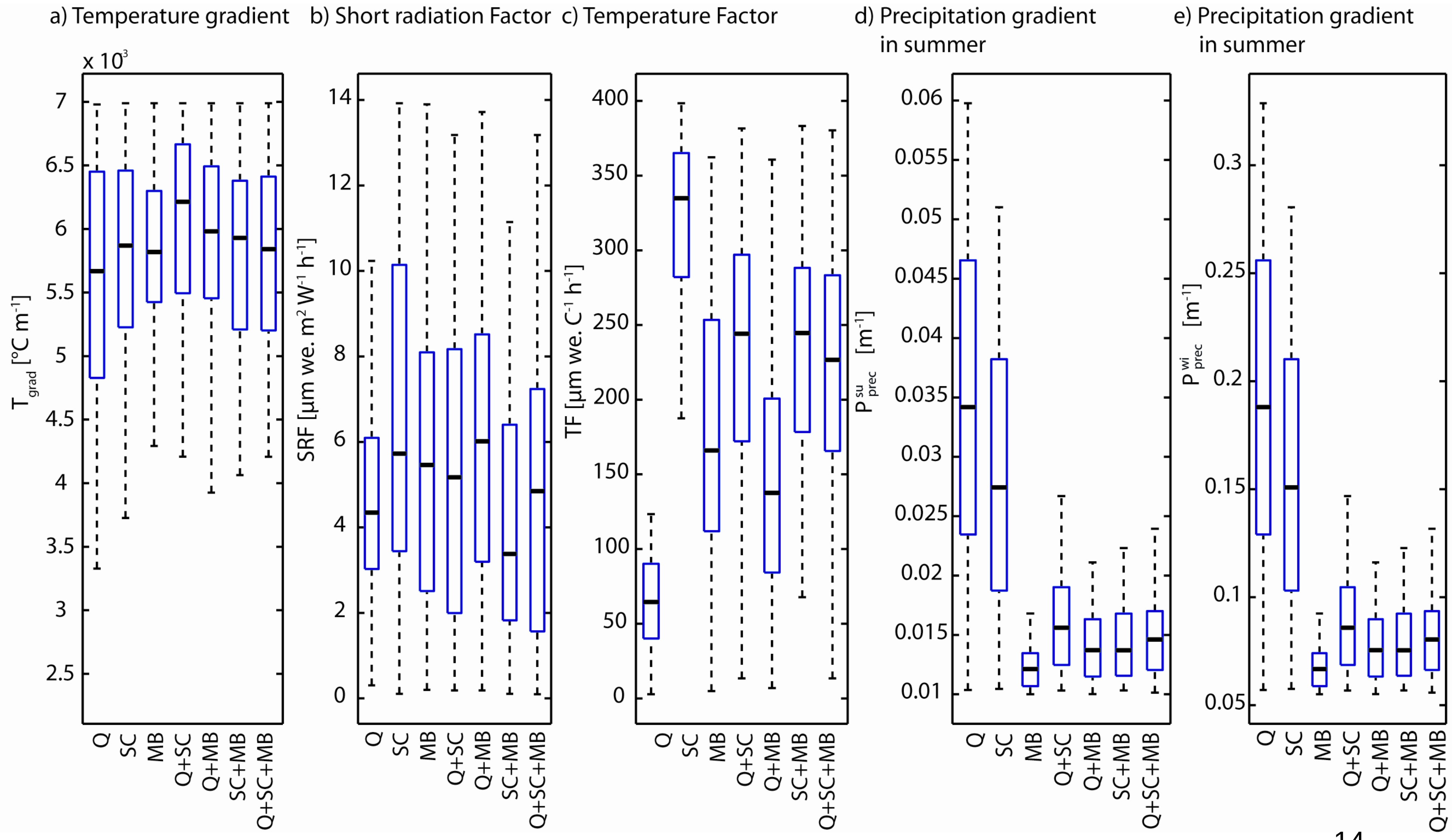
Mean overall performance defined by the average empirical probability

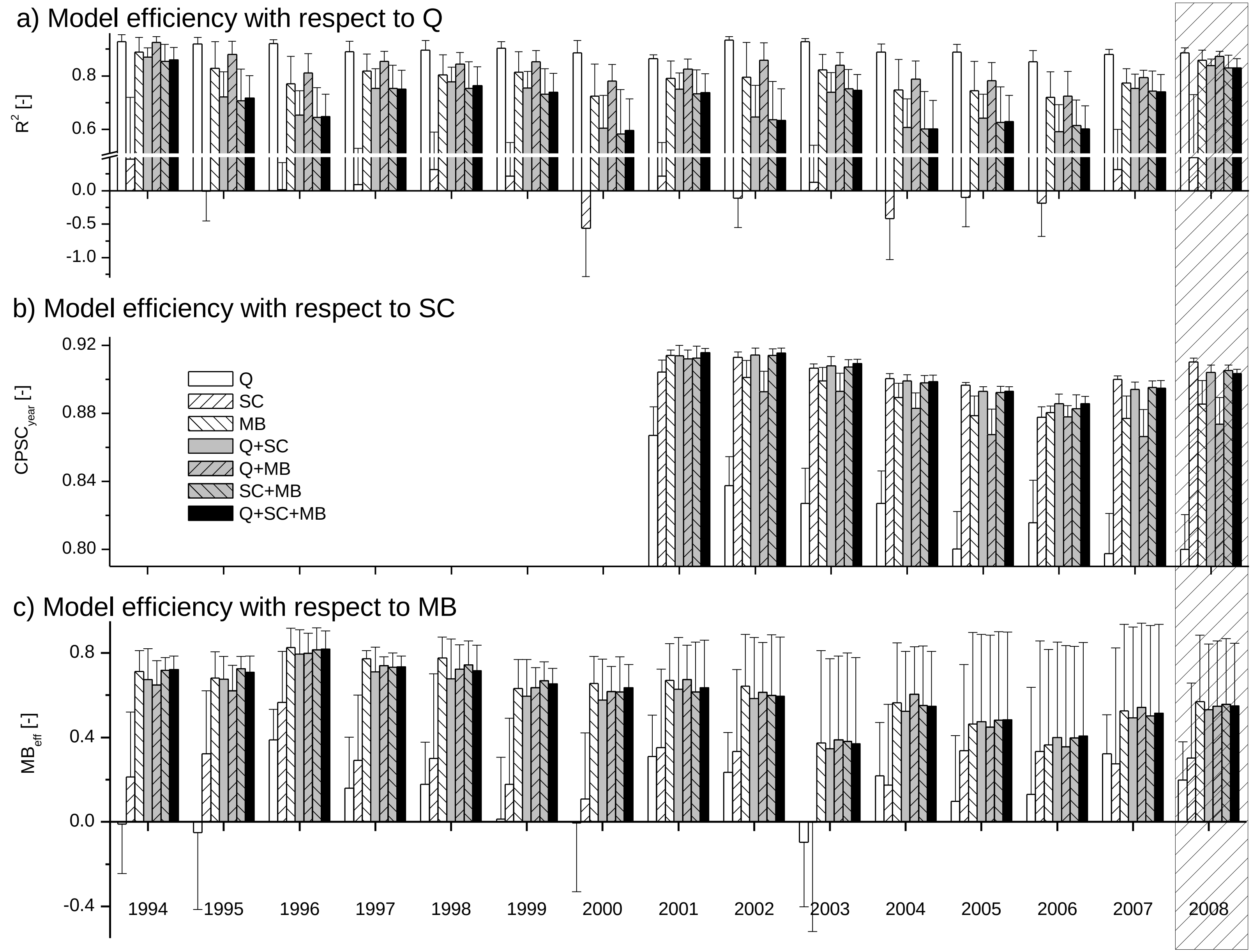


Finger et al. (2011), WRR

Parameter constrainment

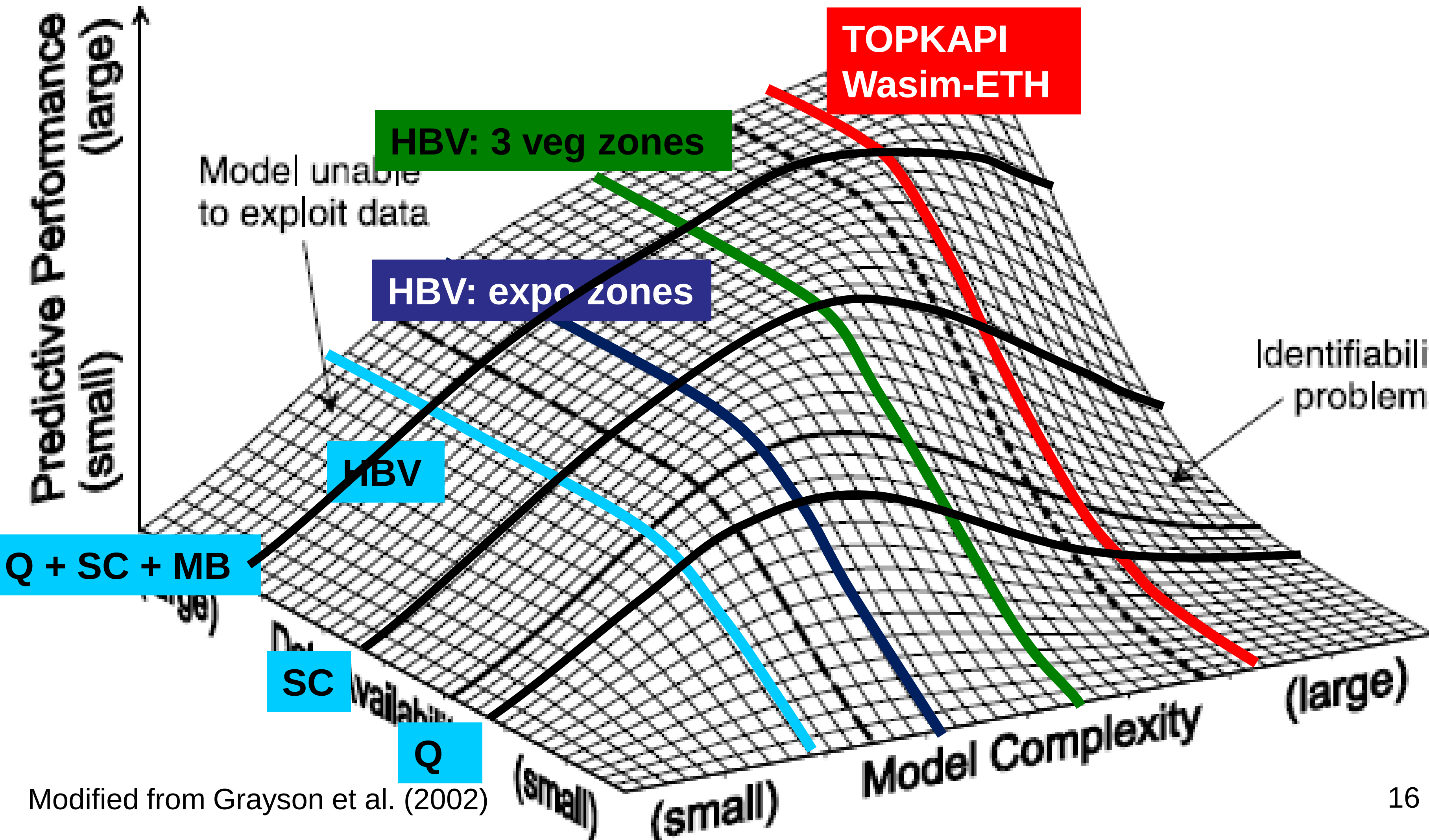


Validation of results



We tested

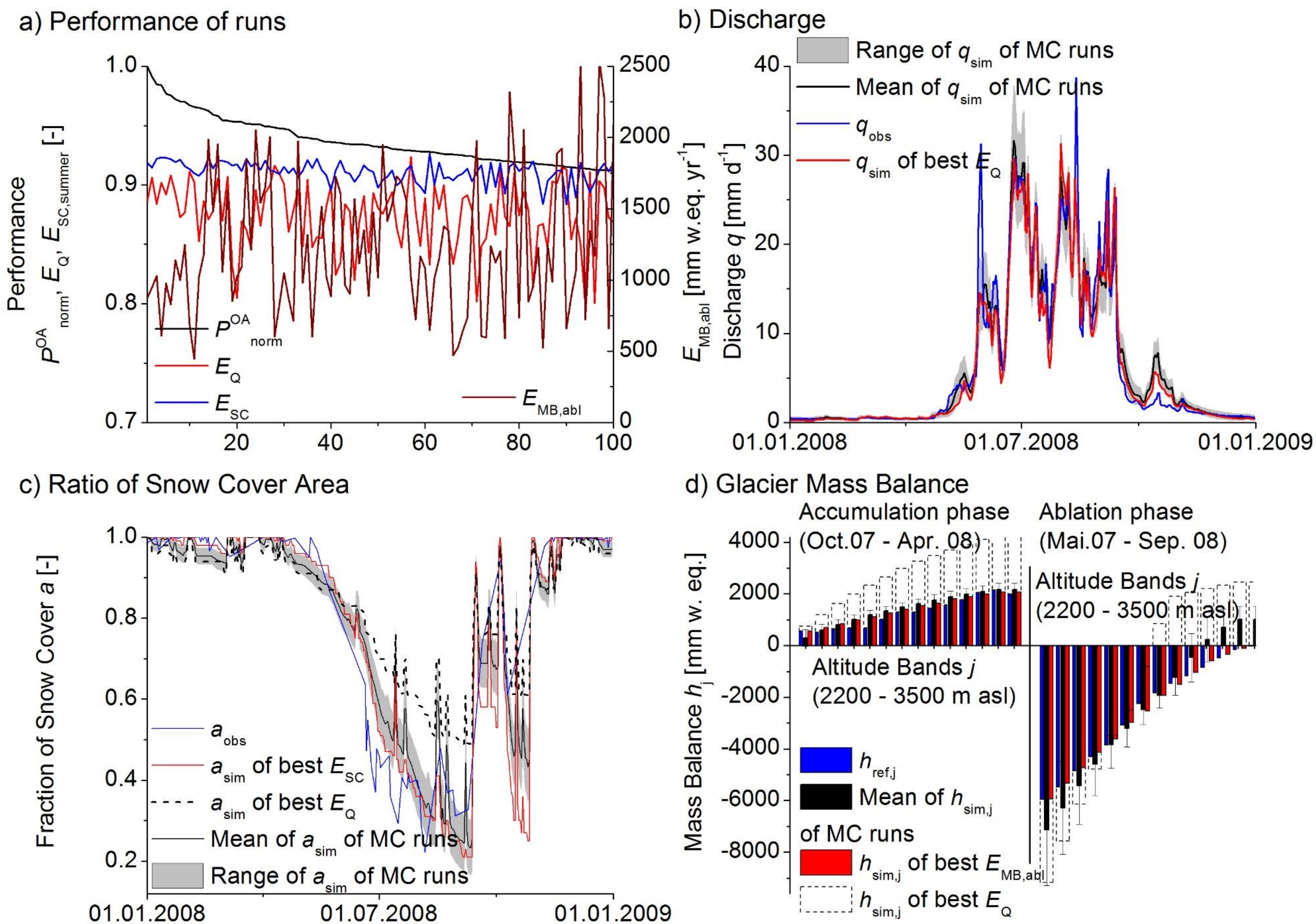
- **4 model complexities (HBV and Topkapi Versions)**
- **Used discharge (Q), snow cover images (SC) and mass balances (MB) for calibration**



Modified from Grayson et al. (2002)

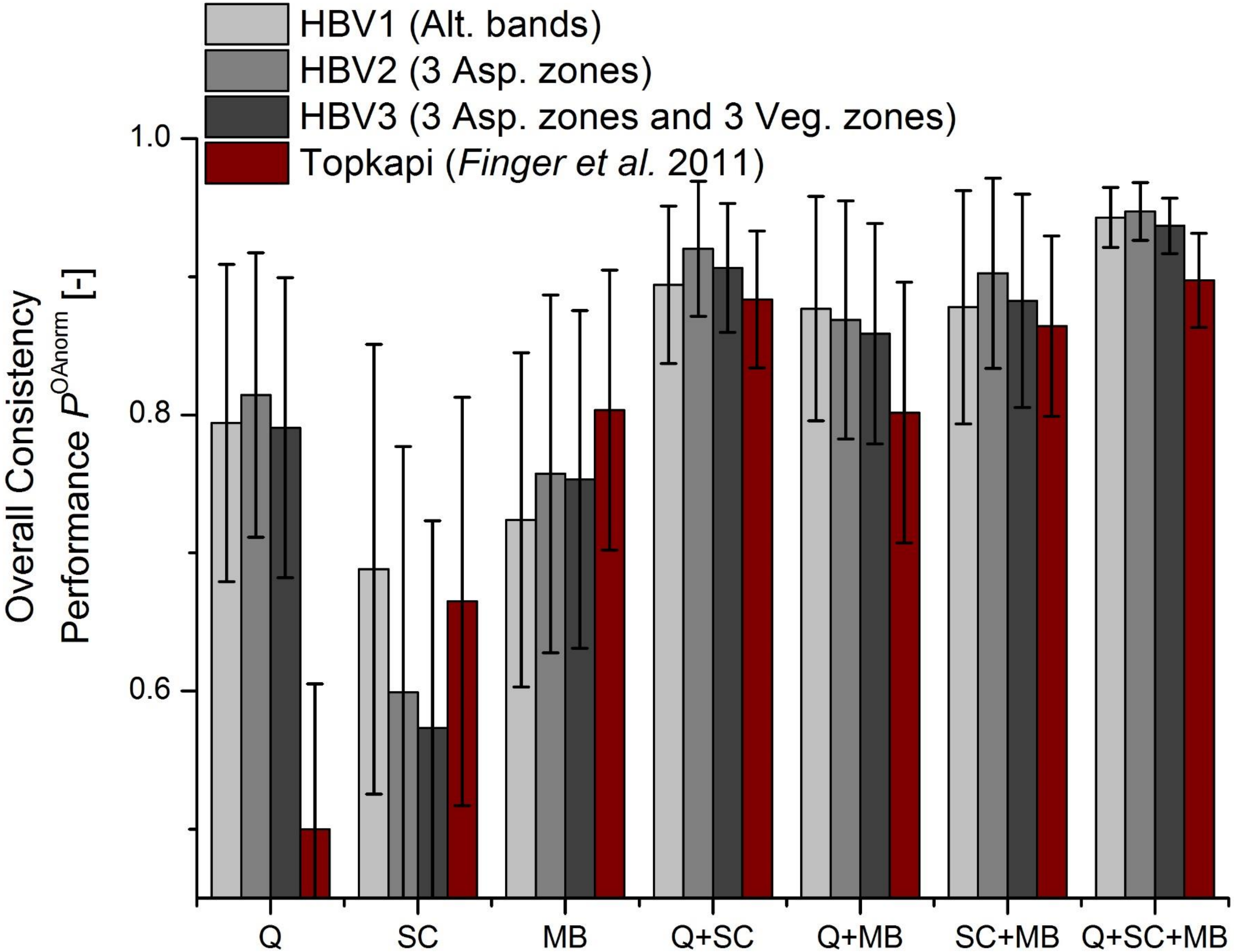
Discussed in Finger et al. (2015)

Results of the 100 best runs from 10'000 MC runs

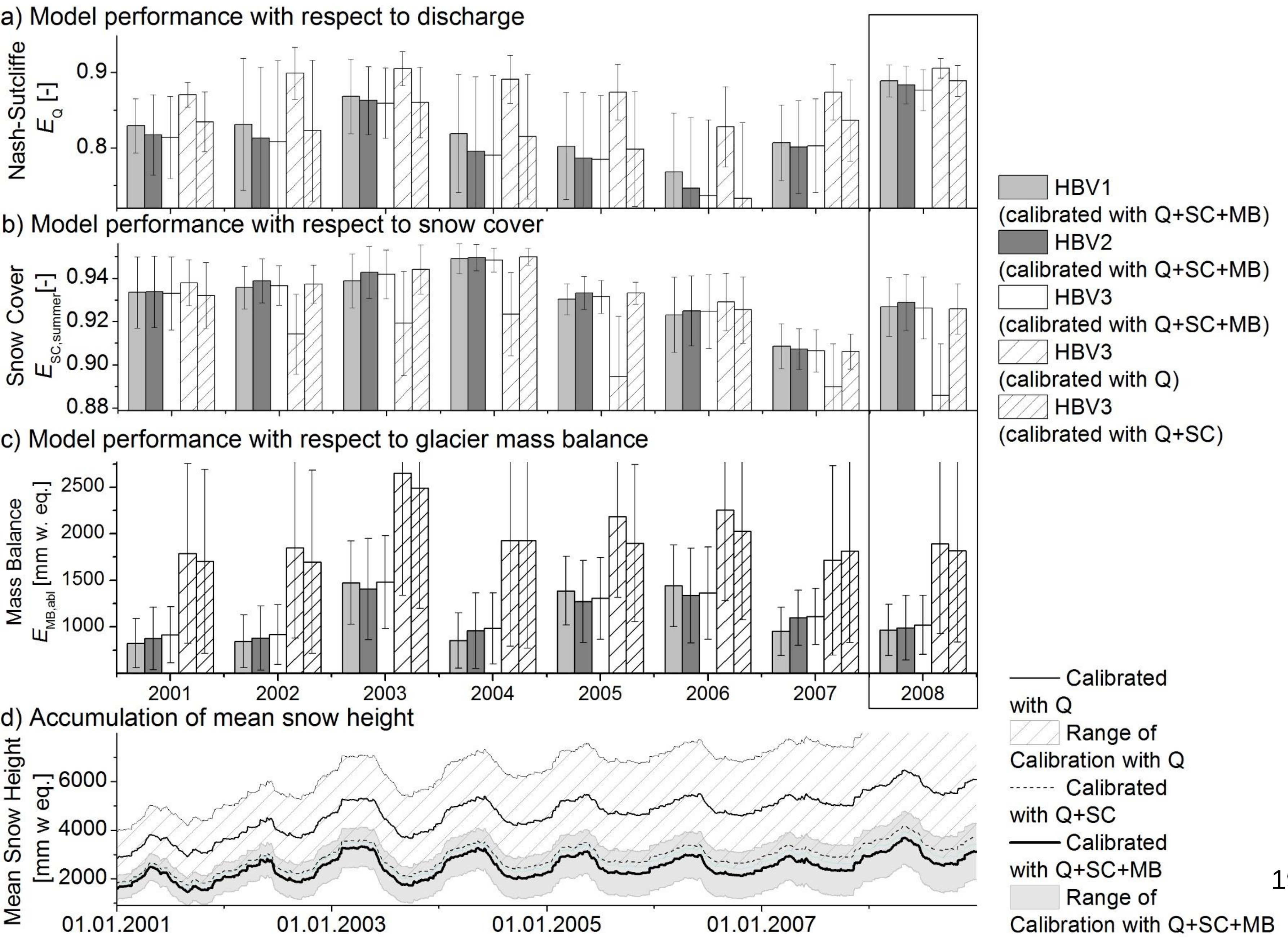


Finger et al. (2015)

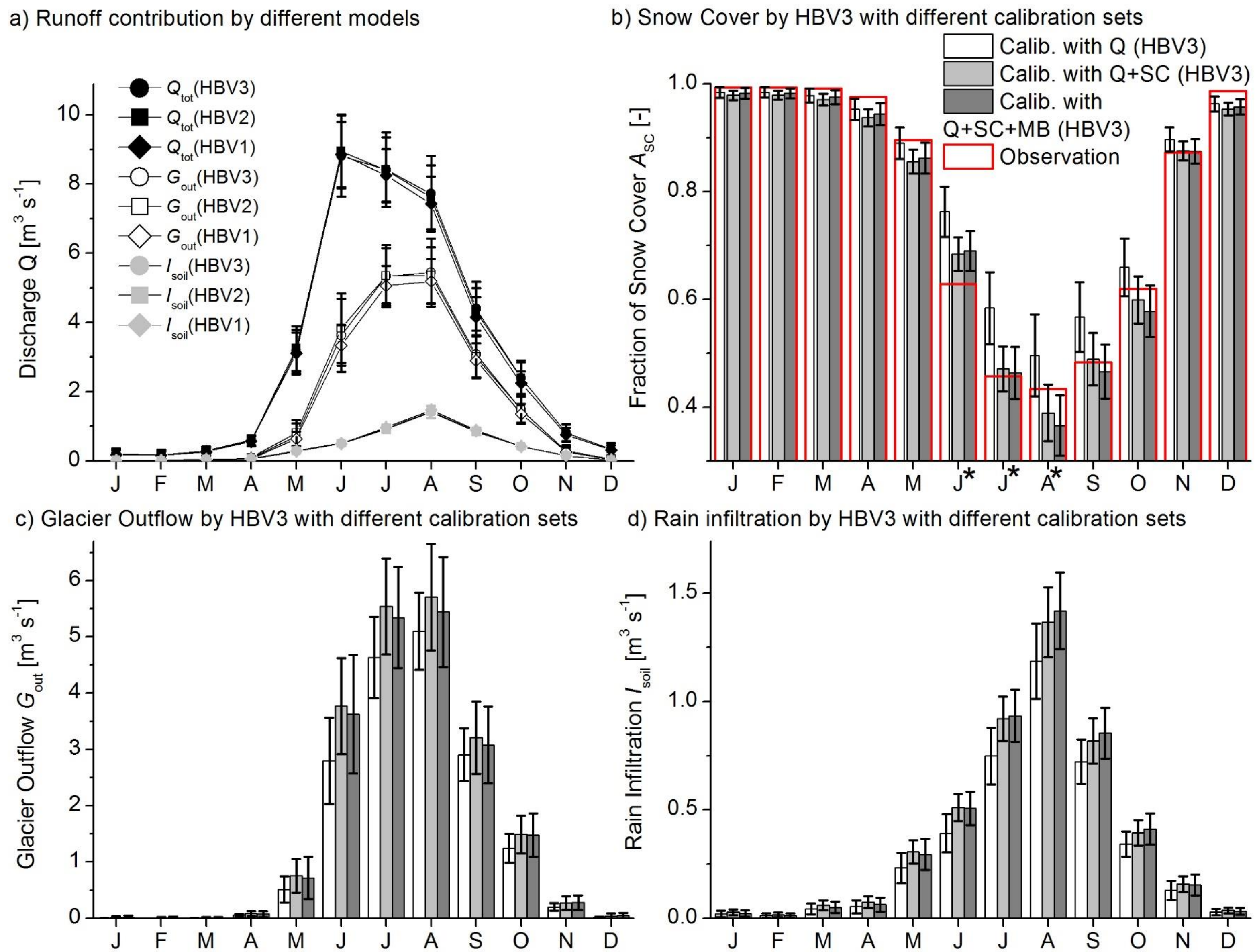
Overall consistency performance of the 4 models



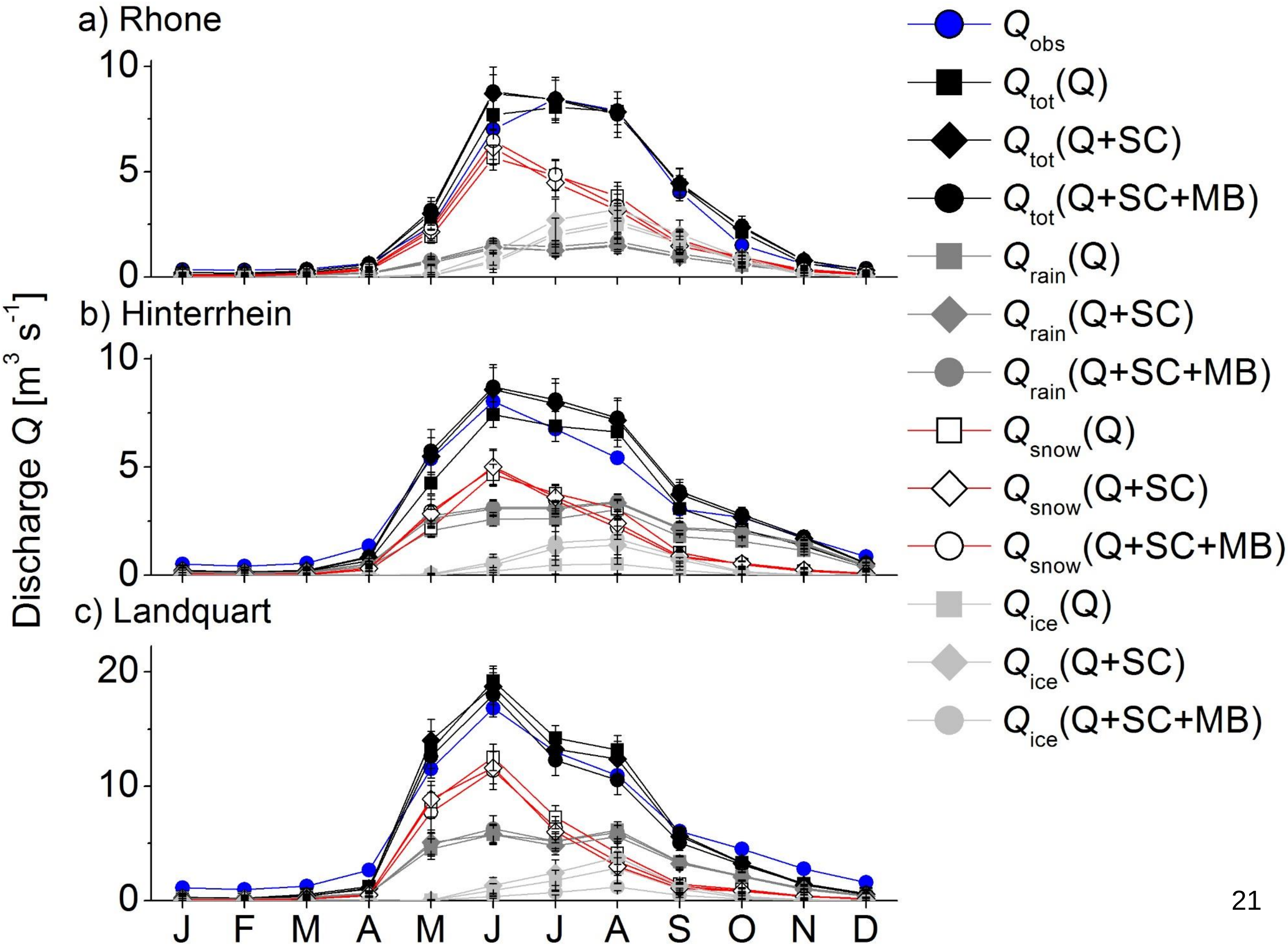
Validation of model performance for a 8-year period



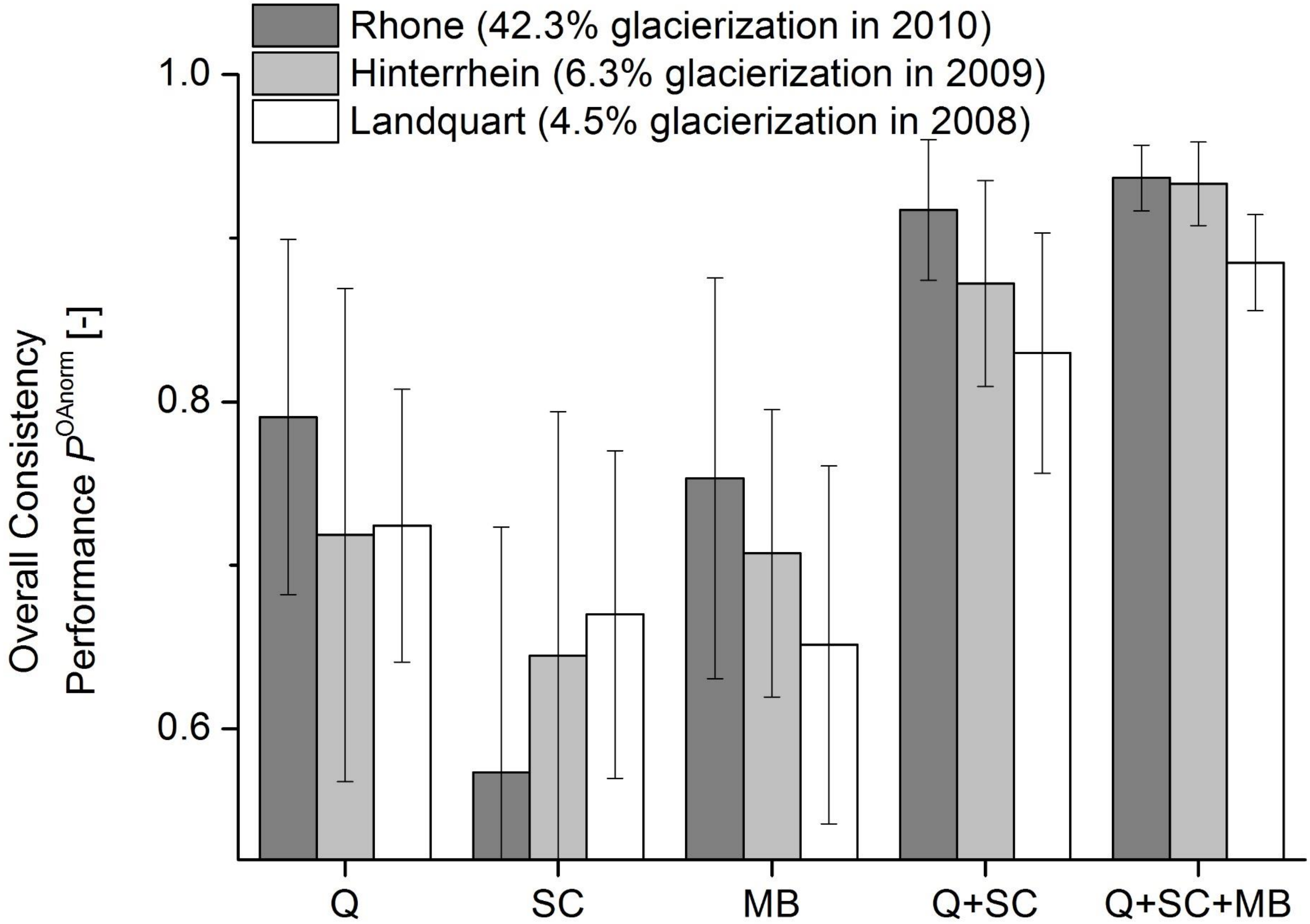
Effects of Model complexity and data availability on results



Final Result: Snow-, Rain- and Glacier-Water in the Rhone



Overall consistency performance for all three study sites



Case study: Projections of climate change impacts on hydropower production

Finger et al. (2012)

Study site: Vispa Valley

Characteristics

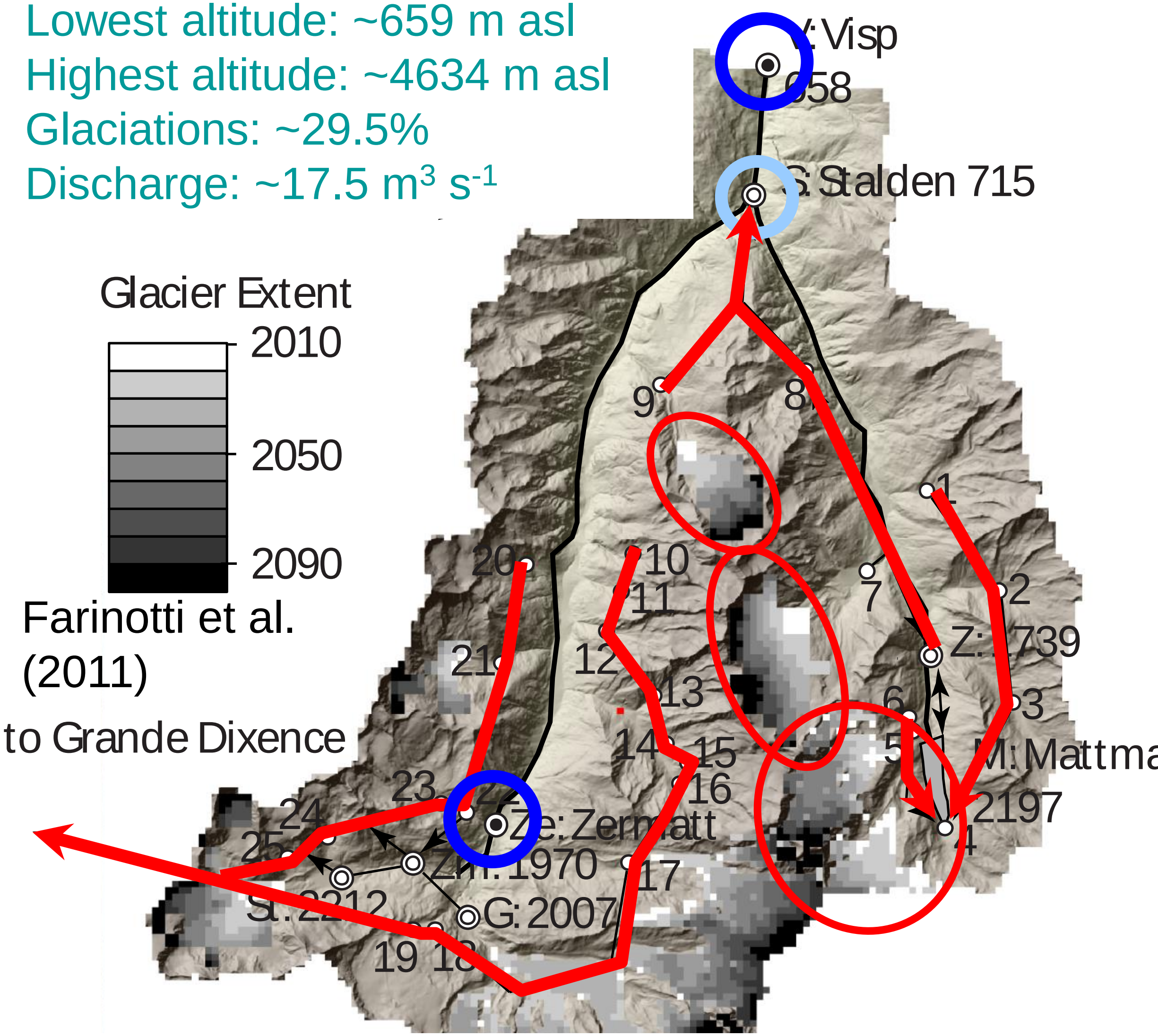
Water shed : 778 km^2

Lowest altitude: ~659 m asl

Highest altitude: ~4634 m asl

Glaciations: ~29.5%

Discharge: ~17.5 m^3 s^{-1}



Gornergletscher: 68 km^2

Mattmarksee: 101Mio m^3

Stalden: 635 GWh yr^{-1}

Peak Prod.: 2360 MW → 2.3 times AKW Gösgen

Model Validation: 2001 - 2008

Lake Level

Input to Reservoir
$R^2 = 0.77$

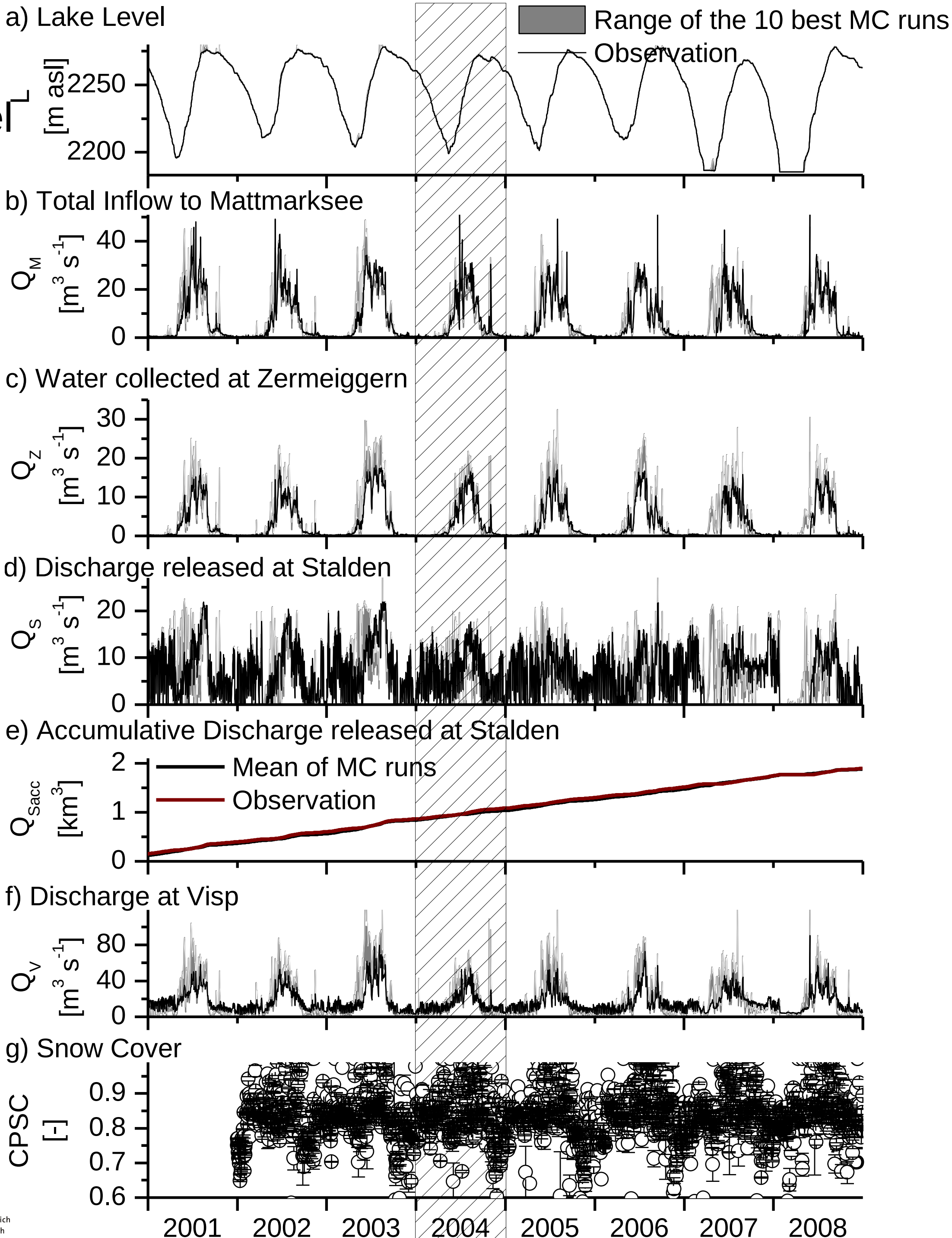
Natural runoff at Zermeiggern
$R^2 = 0.71$

Discharge released in Stalden

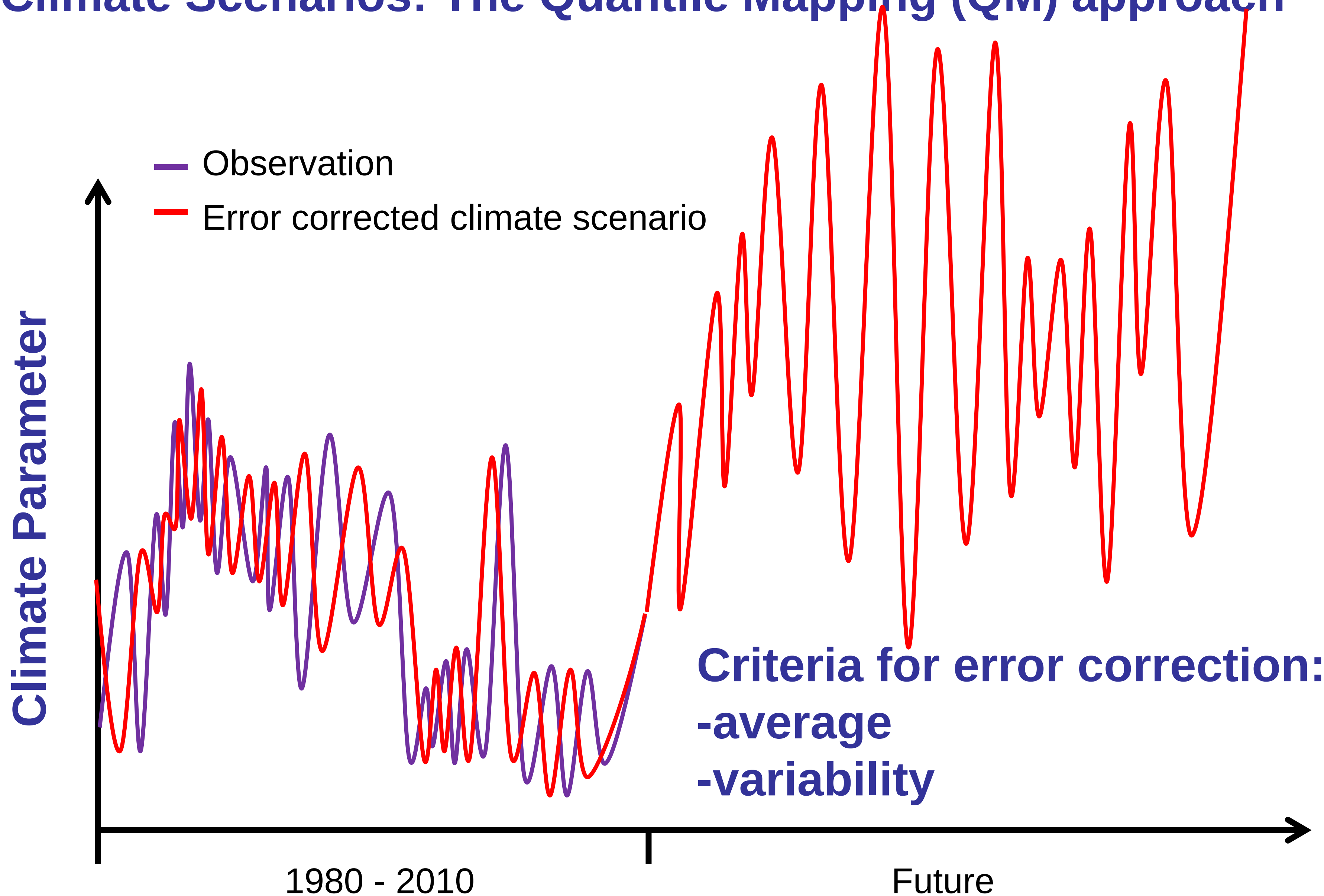
Acc. Discharge released in Stalden
RVE = 0.004

Discharge in Visp
RVE = -0.18

Correctly computed snow cover
Ratio = 0.83



Climate Scenarios: The Quantile Mapping (QM) approach

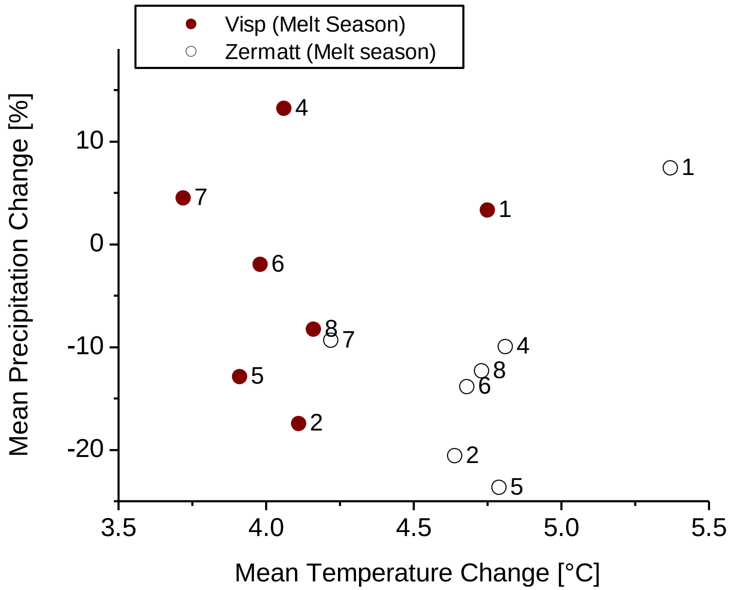


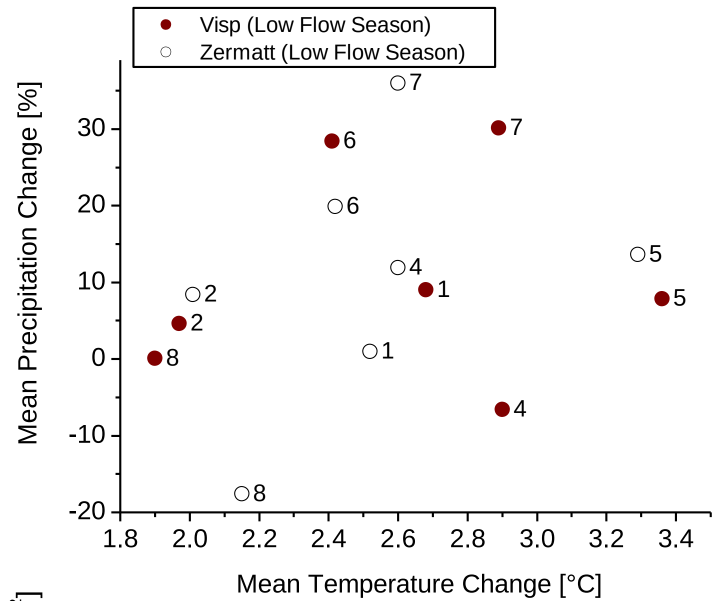
Criteria for error correction:

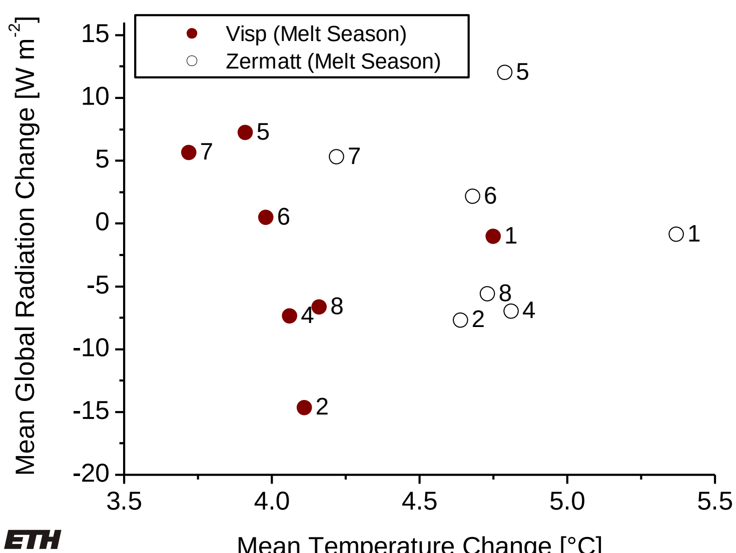
-average

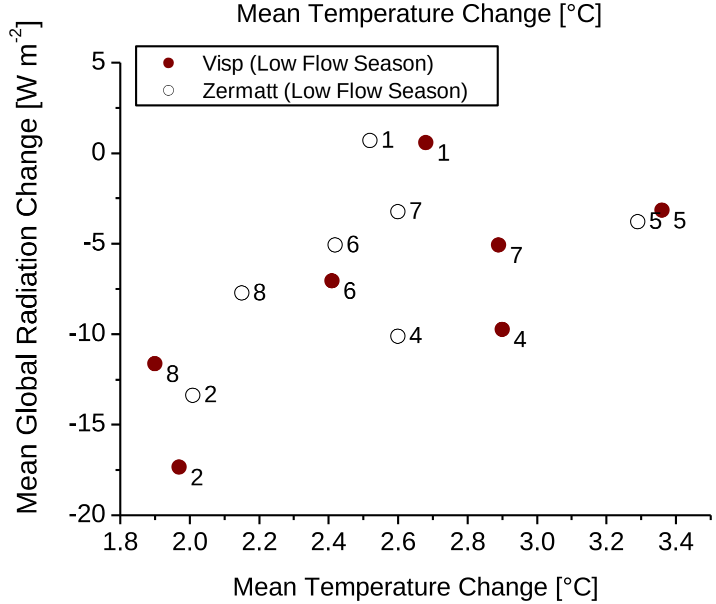
-variability

Seven Climate Scenarios from the ENSEMBLE project: Delta Signal between 2071/2098 and 1992/2019



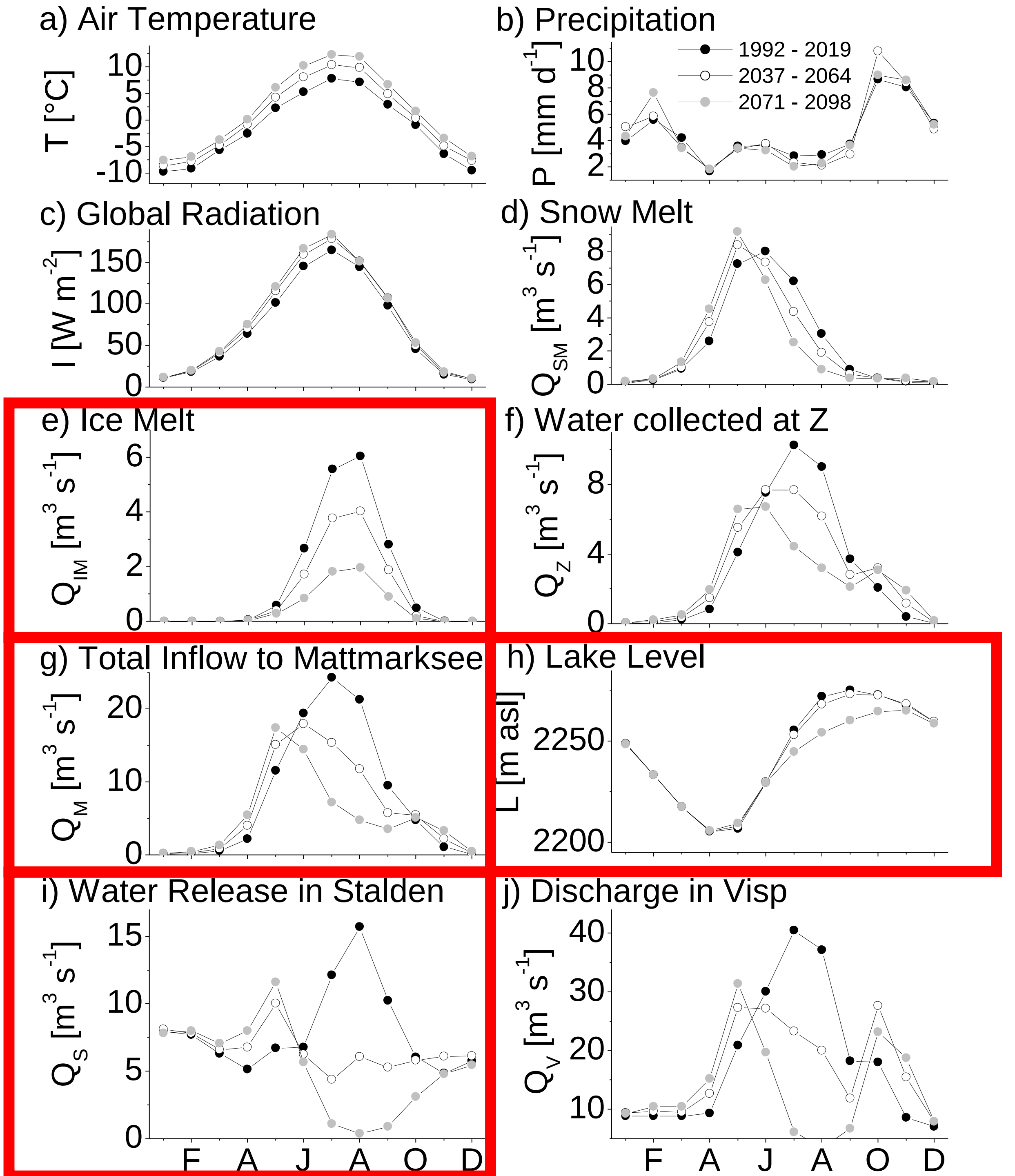






Nr.	GCM	RCM
1	ARPEGE	CNRM-ALADIN5.1
2	ARPEGE	DMI-HIRHAM5
3	HadCM3Q0	ETHZ-CLM
4	HadCM3Q0	HC-HadRM3
5	ECHAM5-r3	KNMI-RACMO2
6	ECHAM5-r3	MPI-REMO
7	BCM	SMHI-RCA

Mean of projected changes based on 210 simulations



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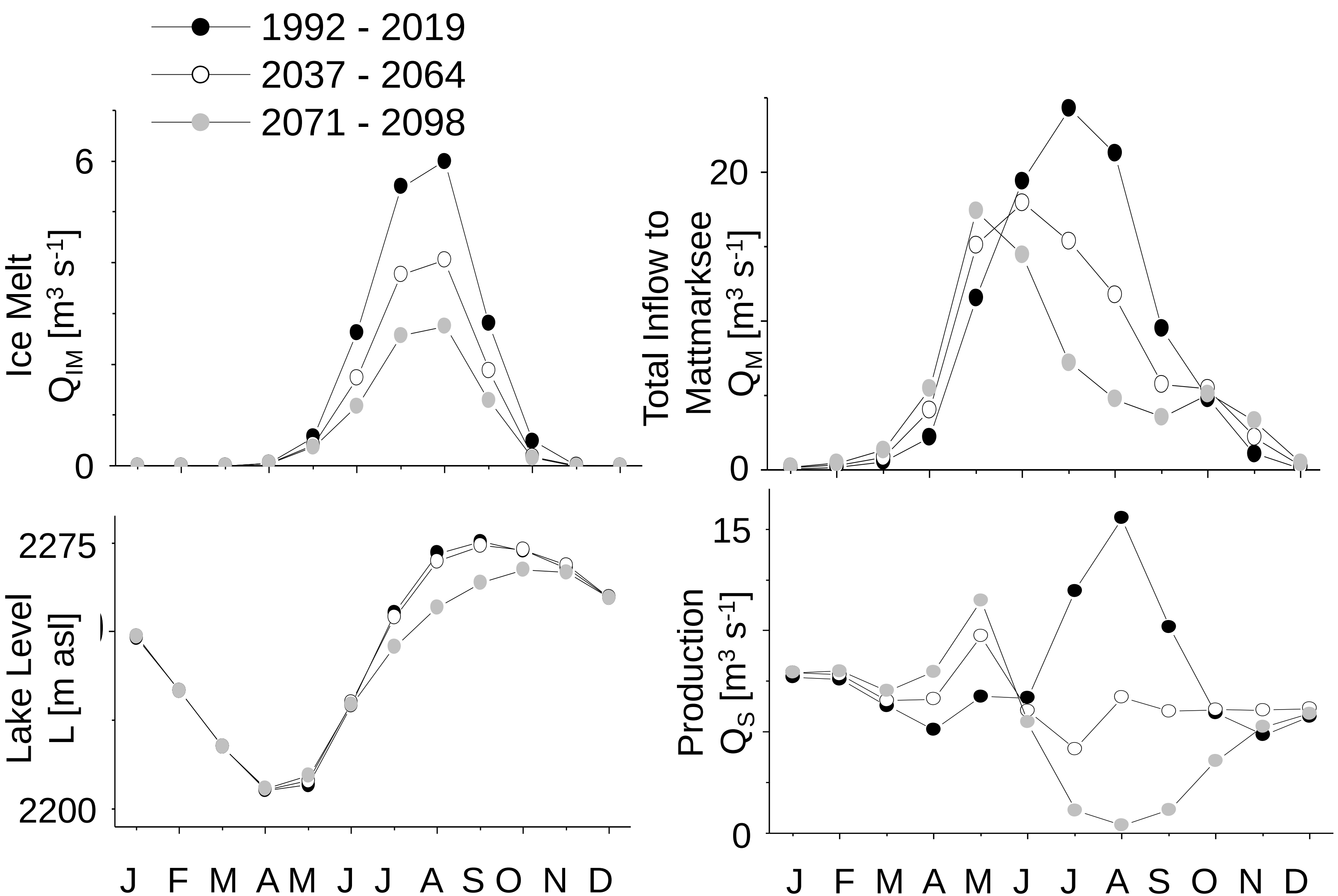
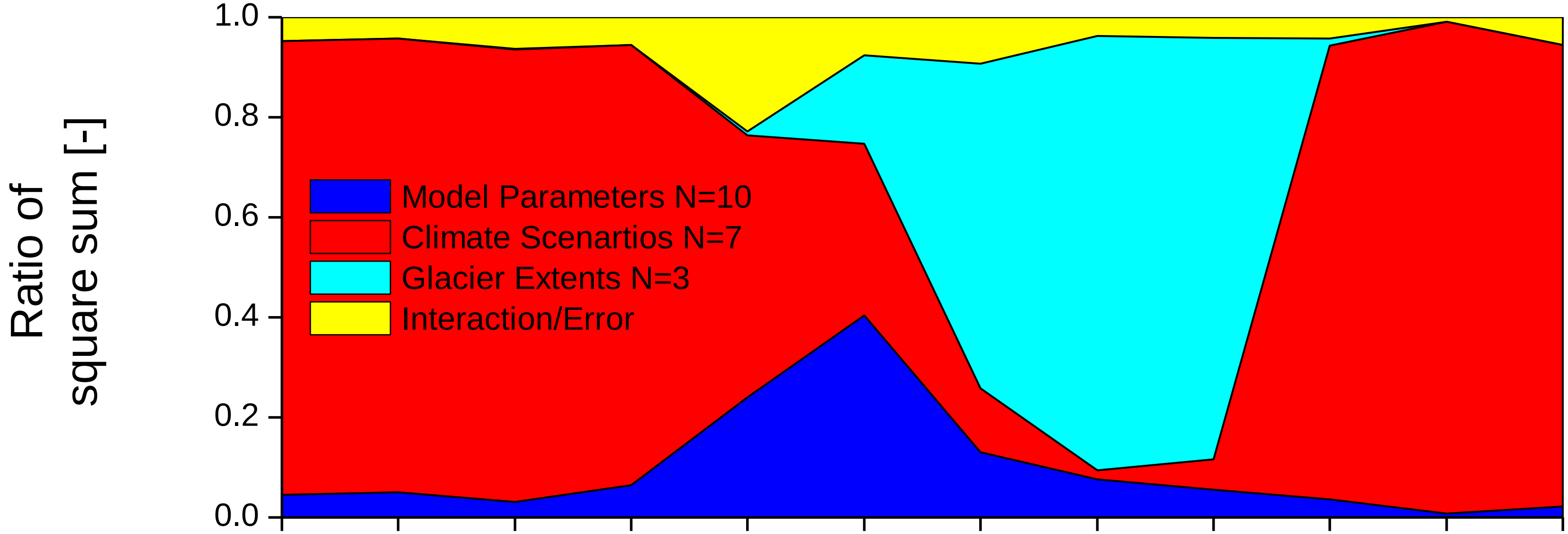
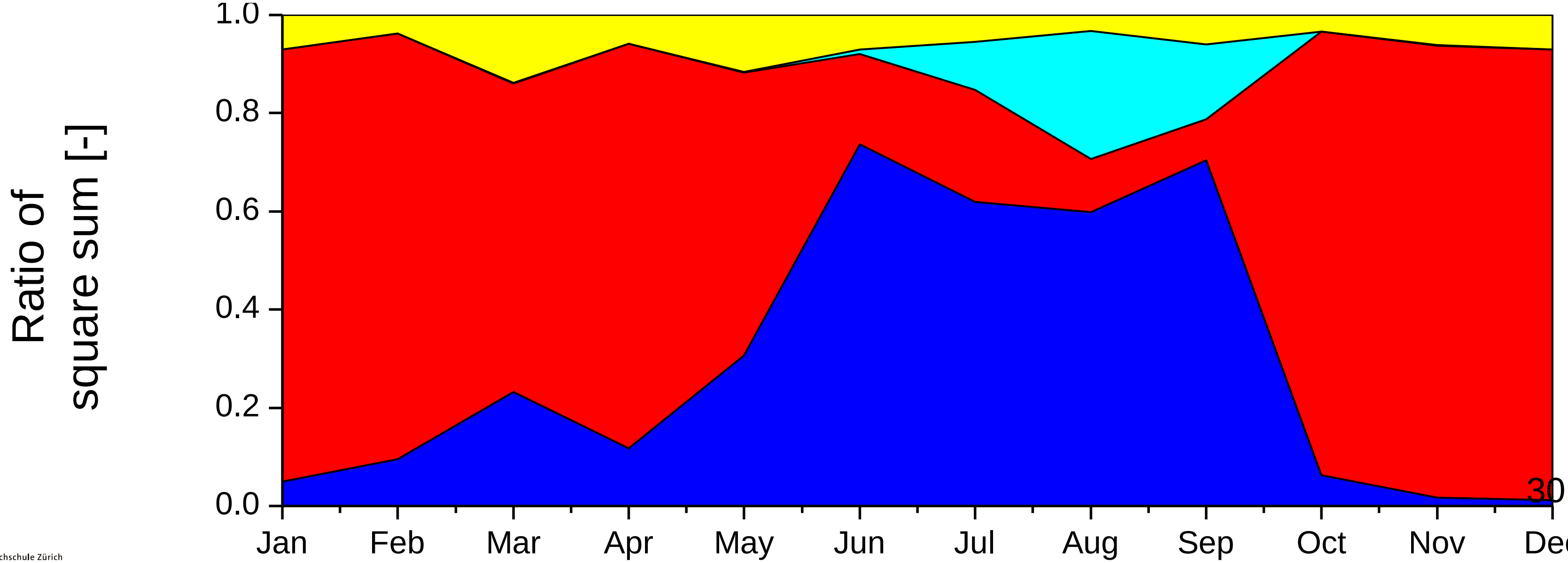


Source of Uncertainty: Analysis of variance (ANOVA)

Medium time-period: 2037-2064

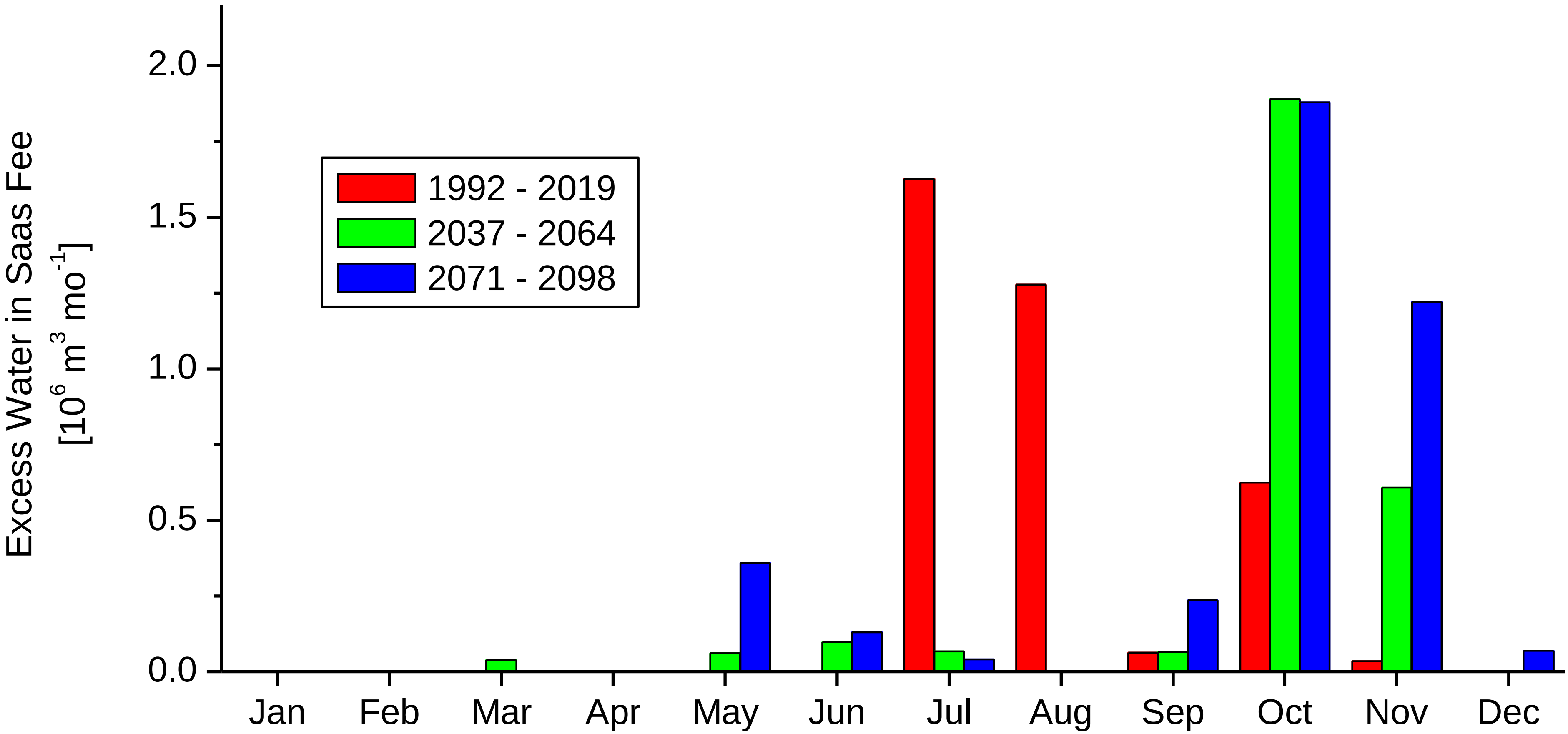


Longterm time-period: 2071-2098

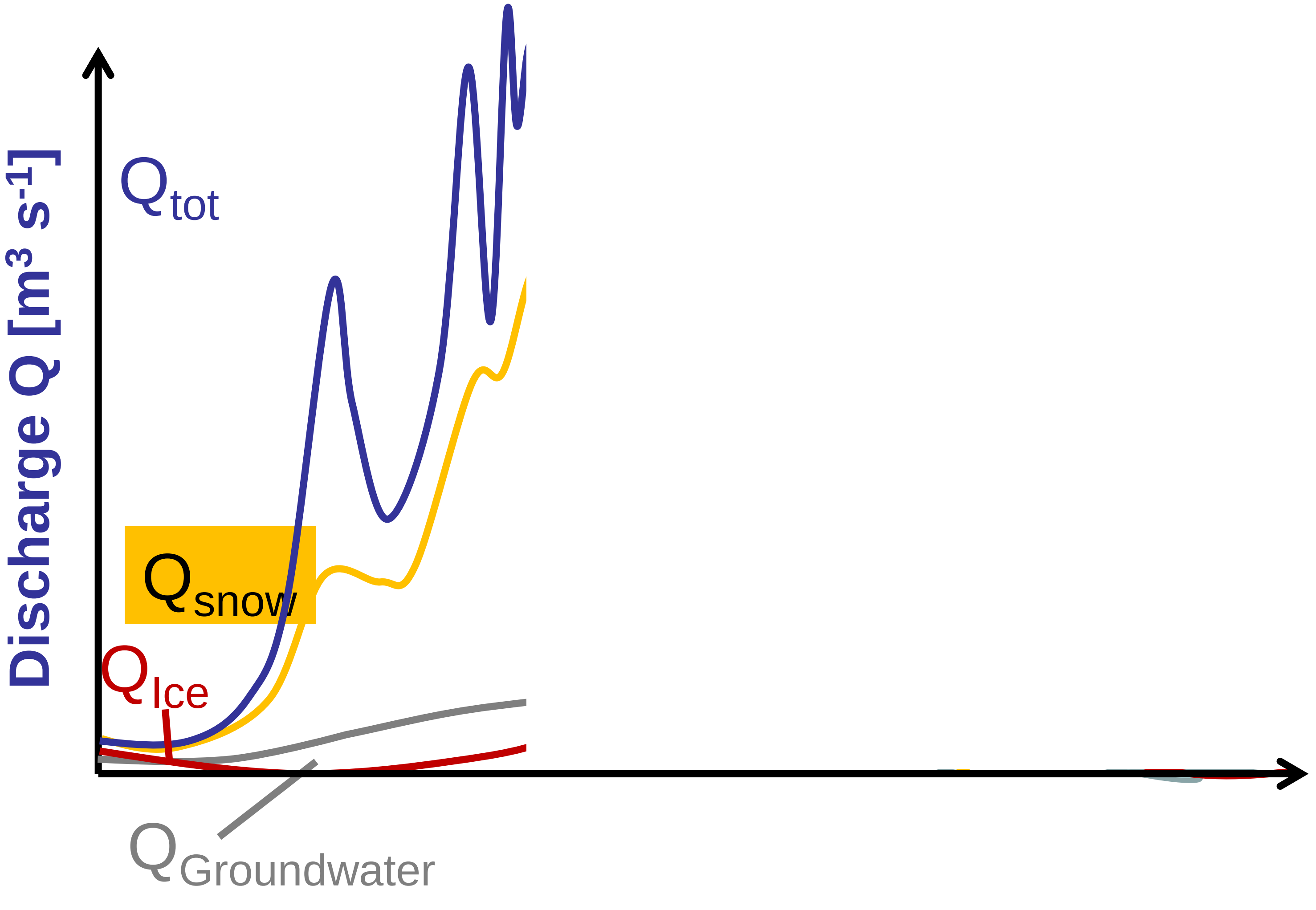


Excess Water

Projections of Excess water in Saas-Fee

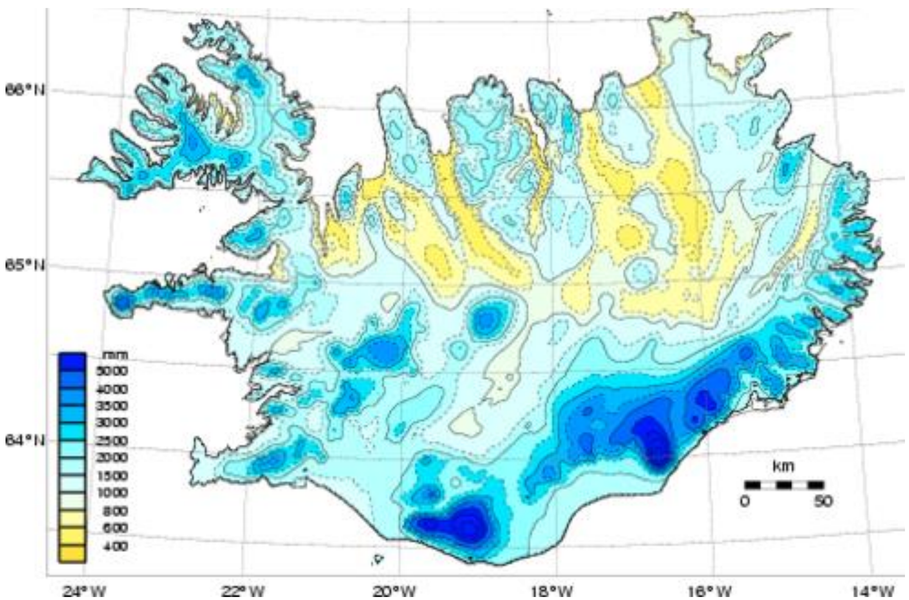


Outlook: Seasonal forecasting of snow, glacier and rainfall runoff



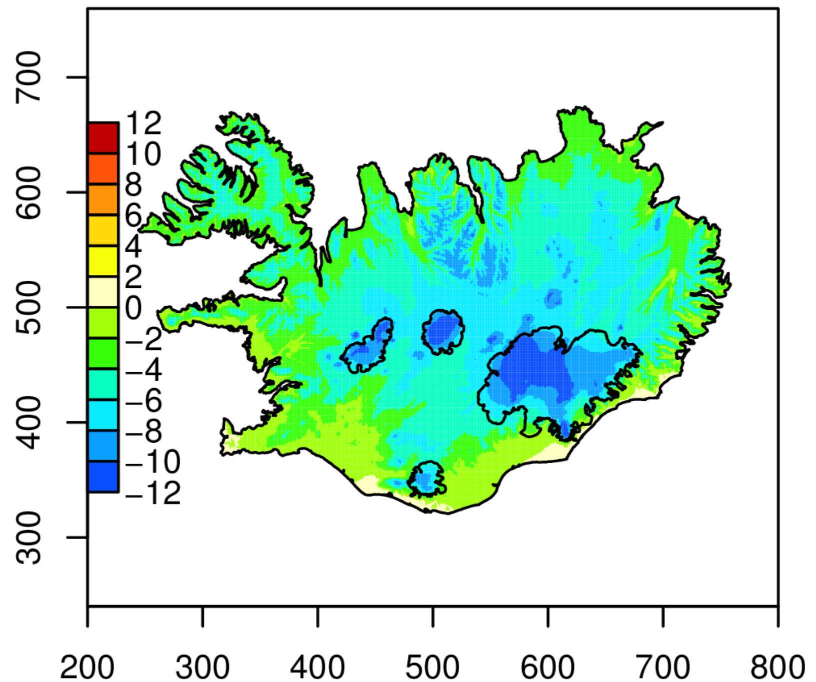
1km gridded datasets to drive hydrological models

Mean Annual Precipitation (1971- 2000)



Crochet et al., 2007,
Jóhannesson et al. 2007

Mean January Temperature (1961 – 1990)



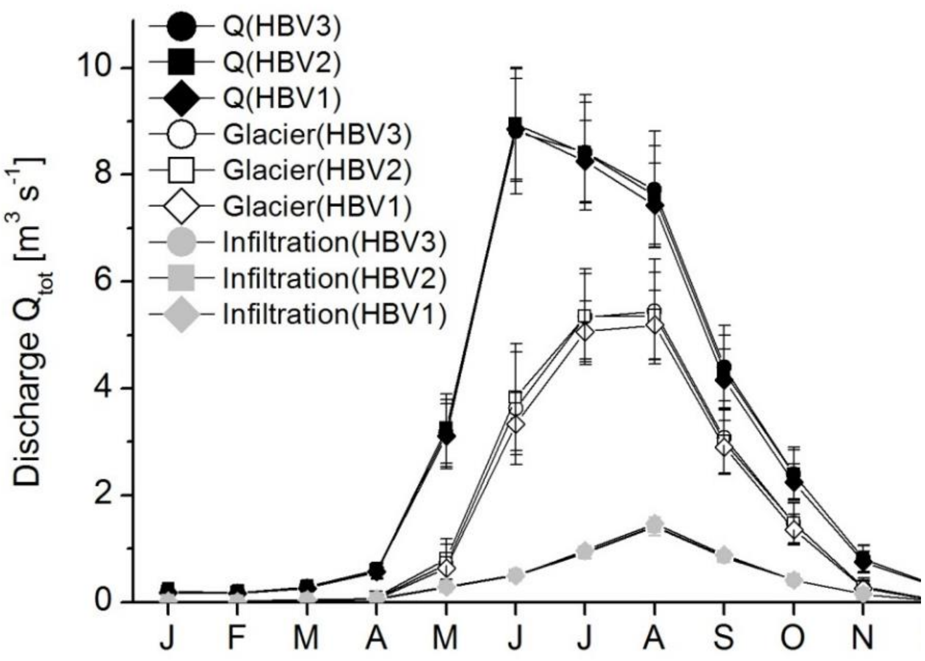
Crochet and Jóhannesson 2011

Methods for hydrological forecasting

48h:
Harmony (NWP) (2.5 km) / statistical correction
Analogue based on ECWMF (1km) → Hydrol. Model → daily Q

3 – 10 days:
ECMWF; deterministic (16km) – EPS (32km) / statistical correction
Analogue based on ECWMF (1km) → Hydrol. Model → daily Q

Up to 7 month (seasonal):
ECMWF – EPS (74km) / statistical correction
→ Hydrol. Model → daily Q, Q_{snow}, Q_{ice}, Q_{Rain}, SWE



ECMWF:
http://www.ecmwf.int/

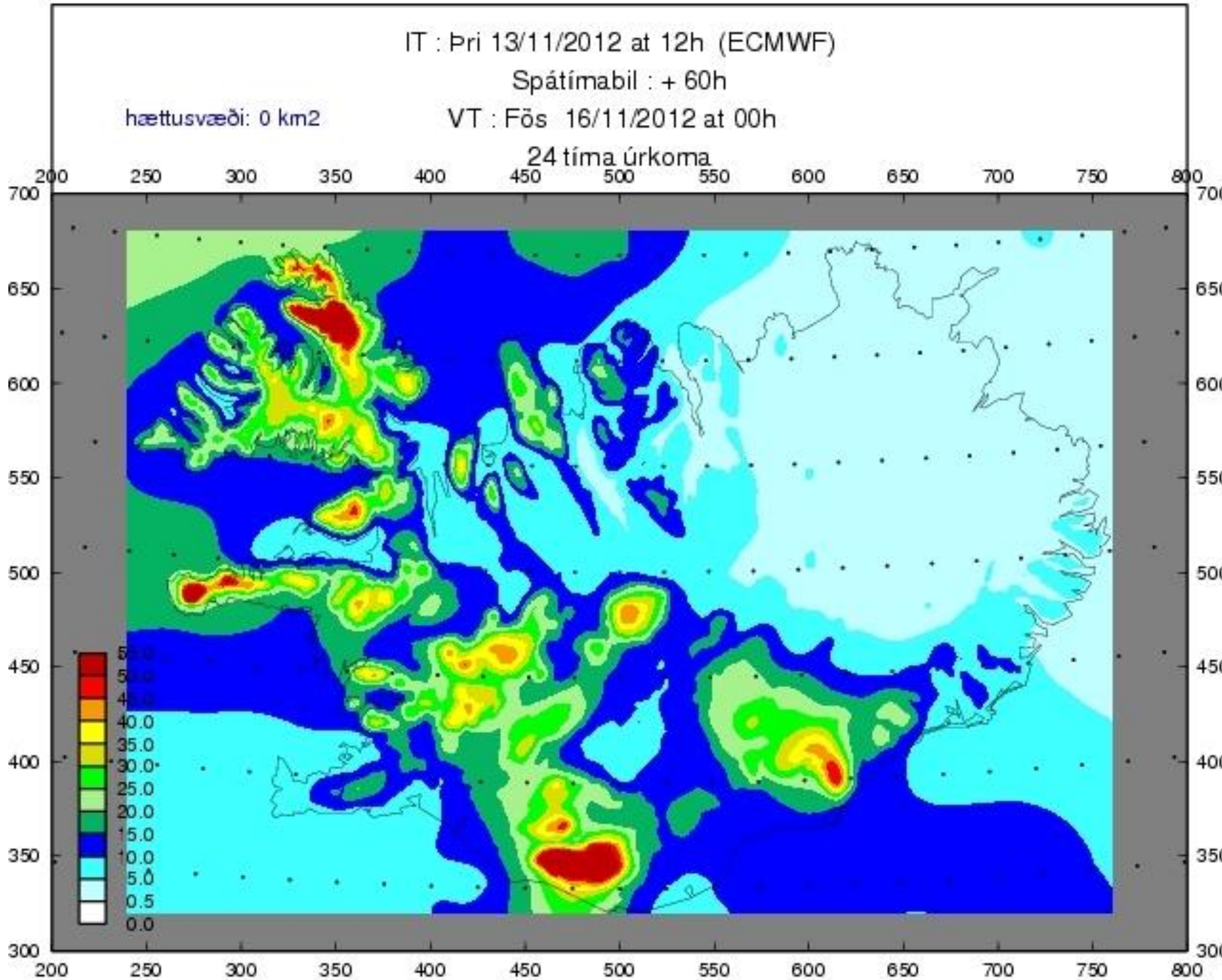
Example of statistical processing of precipitation forecasts

ECMWF

Statistical correction

Post processed ECM:

- 1km resolution
- Consistent with gridded data used for calibration of hydrological model

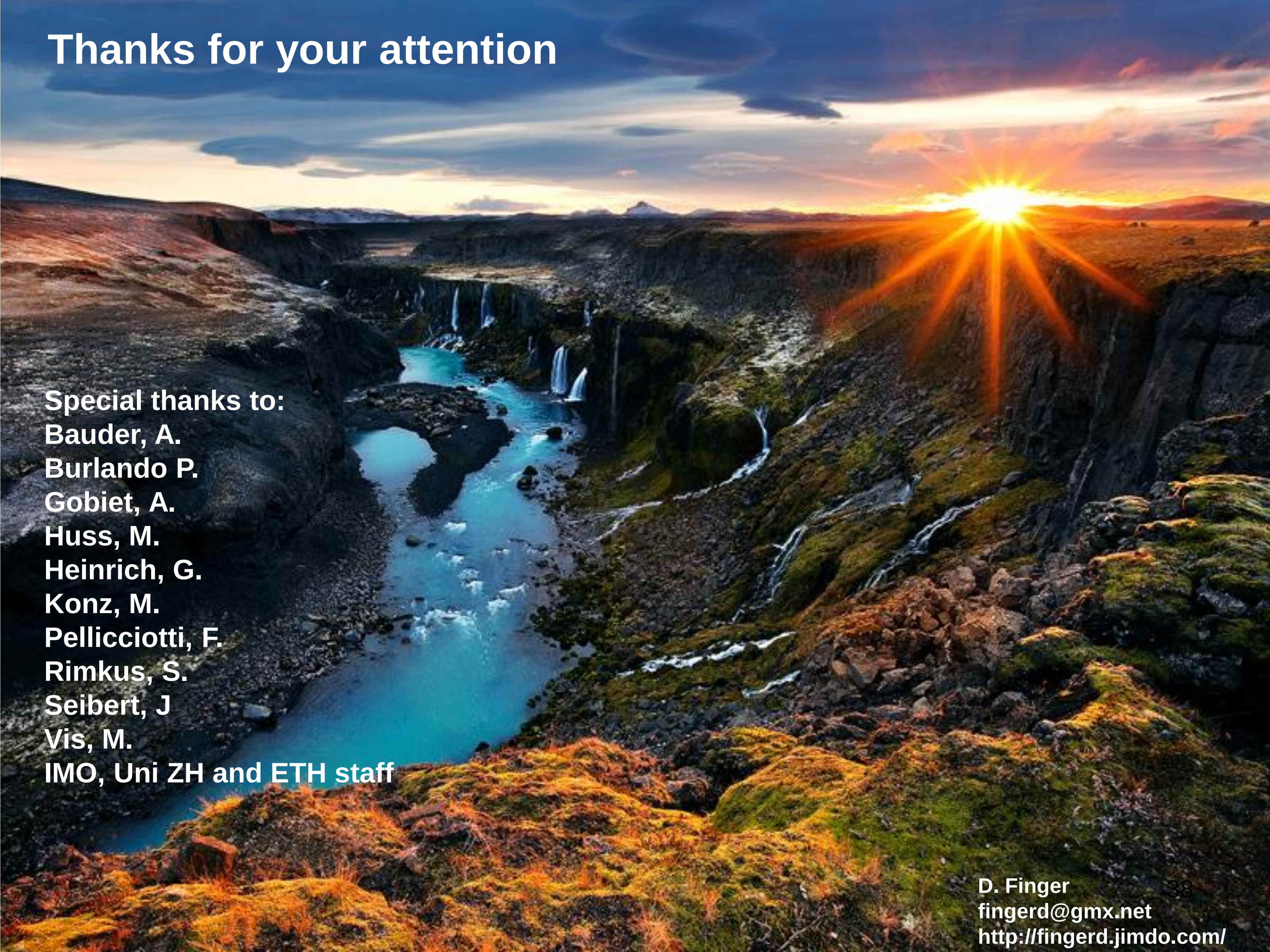


Crochet, unpublished, © IMO

Conclusions

- Multi variable calibration increases overall performance
  - Q and SC are a good combination
- Model complexity does not increase performance
  - The three HBV version revealed similar performance
- The value of SC increases with decreasing glaciation
- The method can easily be applied to any headwater

We are still looking for collaboration on Horizon2020 calls



Thanks for your attention

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Rimkus, S.
Seibert, J
Vis, M.
IMO, Uni ZH and ETH staff

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References:

Finger, D., A. Hugentobler, M. Huss, A. Voinesco, H.R. Wernli, D. Fischer, E. Weber, P-Y. Jeannin, M. Kauzlaric, A. Wirz, T. Vennemann, F. Hüsler, B. Schädler, and R. Weingartner (2013). Identification of glacial melt water runoff in a karstic environment and its implication for present and future water availability. Hydrol. Earth Syst. Sci. Discuss. 10, 1-45, doi: 10.5194/hessd-10-1-2013.

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Crochet, P (2013). Sensitivity of Icelandic river basins to recent climate variations. Jökull, 71-90, No. 63.

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