# The value of satellite retrieved snow cover images to assess water resources and the hydropower potential of ungauged mountain areas

COST ES1404, Snow hydrology workshop, Reykjavik, Iceland

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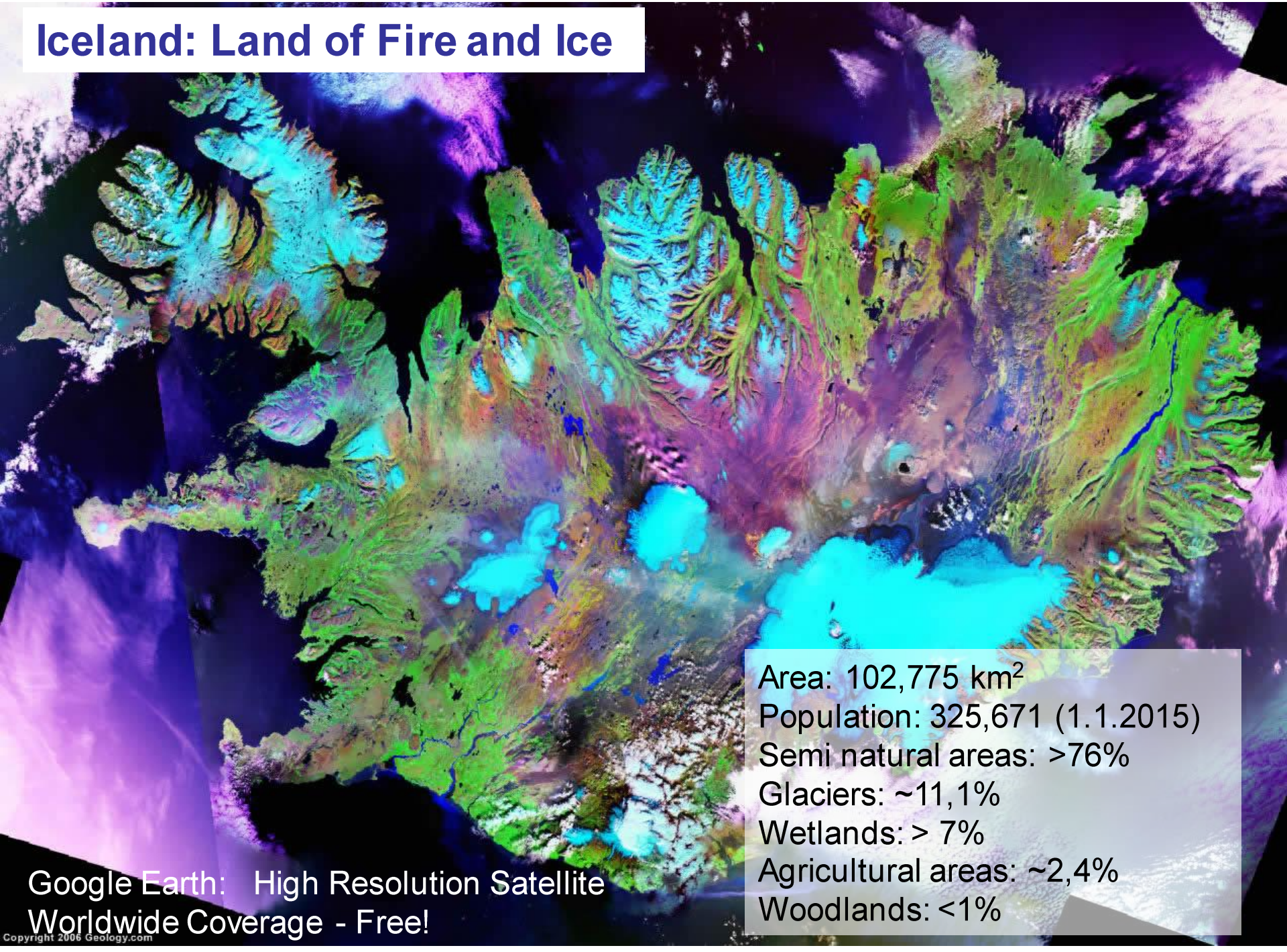
HÁSKÓLINN Í REYKJAVÍK
REYKJAVIK UNIVERSITY

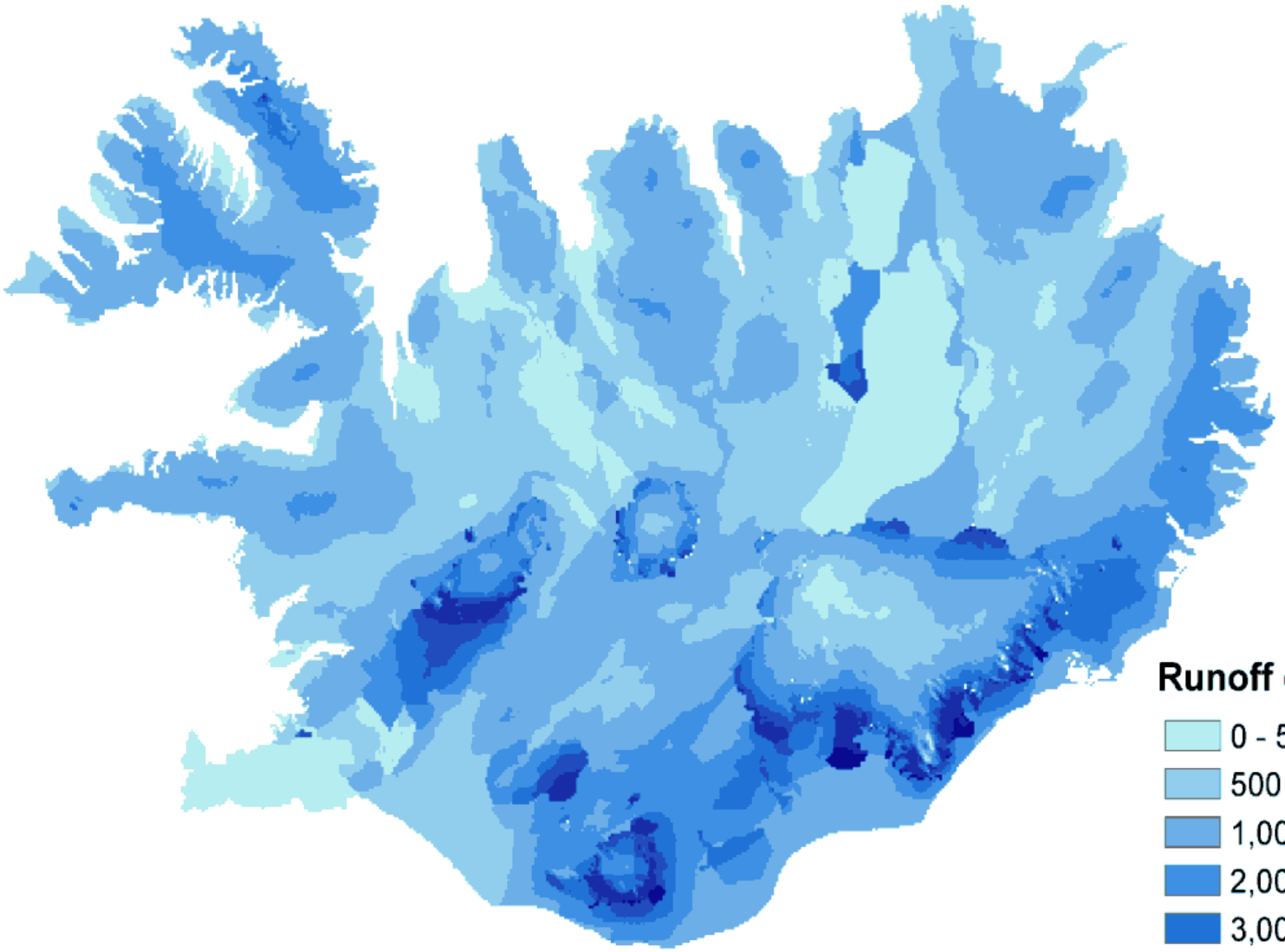
# Iceland: Land of Fire and Ice



Area: 102,775 km$^2$
Population: 325,671 (1.1.2015)
Semi natural areas: >76%
Glaciers: ~11,1%
Wetlands: > 7%
Agricultural areas: ~2,4%
Woodlands: <1%

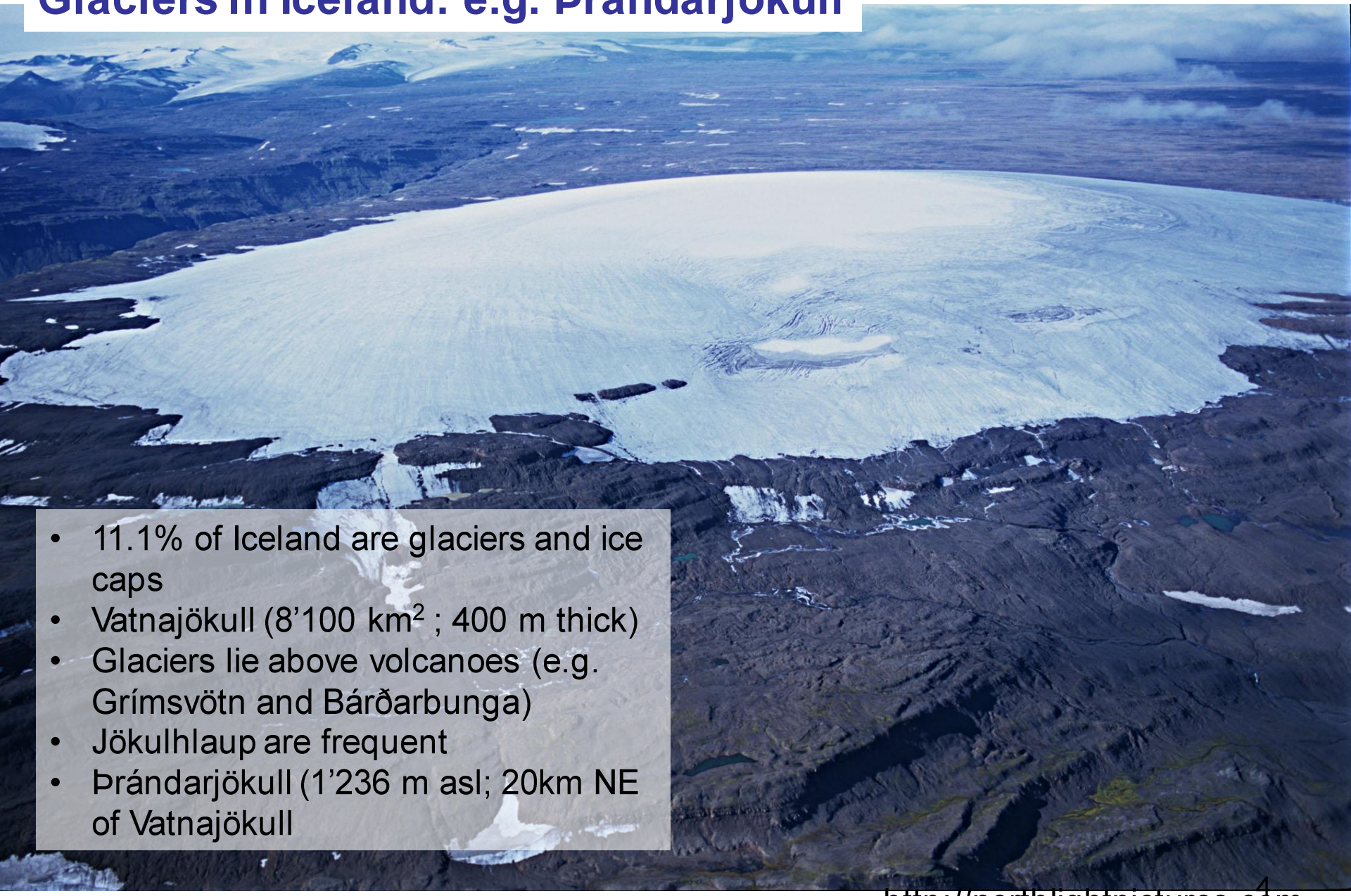
Google Earth: High Resolution Satellite
Worldwide Coverage - Free!

# Water resources in Iceland




Jónsdóttir, 2007

# Glaciers in Iceland: e.g. Þrándarjökull



- 11.1% of Iceland are glaciers and ice caps
- Vatnajökull (8'100 $km^2$ ; 400 m thick)
- Glaciers lie above volcanoes (e.g. Grímsvötn and Bárðarbunga)
- Jökulhlaup are frequent
- Þrándarjökull (1'236 m asl; 20km NE of Vatnajökull

http://northlightpictures.com

# Emerging water sources: e.g. Hraunfossar, IS

- Borgarfjörður, western Iceland
- Meltwater from Langjökull flows through a lava field into the Hvítá river (200 $m^3$ $s^{-1}$)
- Hydrologic Connectivity is importnat

# Jökulhlaups: e.g. River Skeiðará

- is a 30 km long glacier river
- Its source is the glacier Skeiðarárjökull (part of Vatnajökull)
- during Jökulhlaup discharge is estimated to reach 45,000 $m^3s^{-1}$
- 880 m long bridge

# Hydropower: e.g. Kárahnjúkavirkjun, IS

Kárahnjúkavirkjun (690 MW; 4600 GWh)
→ Base power

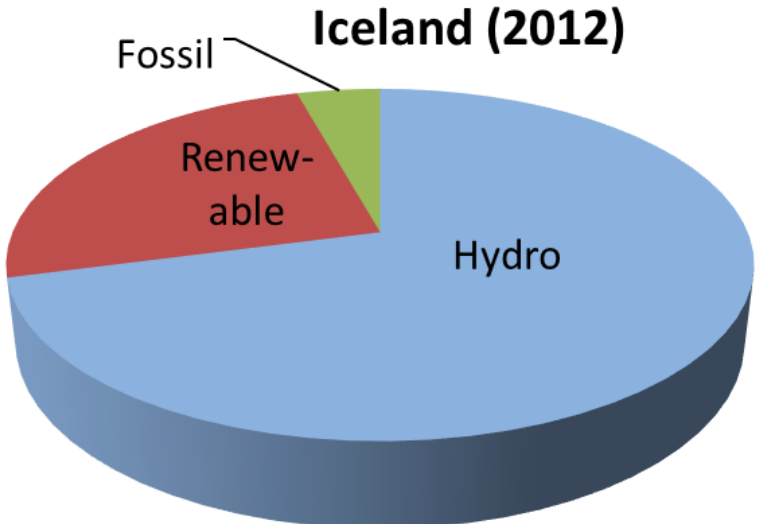
# Motivation


Annual Hydropower Production:

| | |
|---|---|
| EU: | ~398 TWh |
| Norway: | ~122 TWh |
| Austria: | ~37 TWh |
| Switzerland: | ~35 TWh |
| Iceland: | ~12 TWh |

Pot: 220 TWh/yr

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




Iceland: Kárahnjúkavirkjun ( 690 MW; 4600 GWh) → Base power

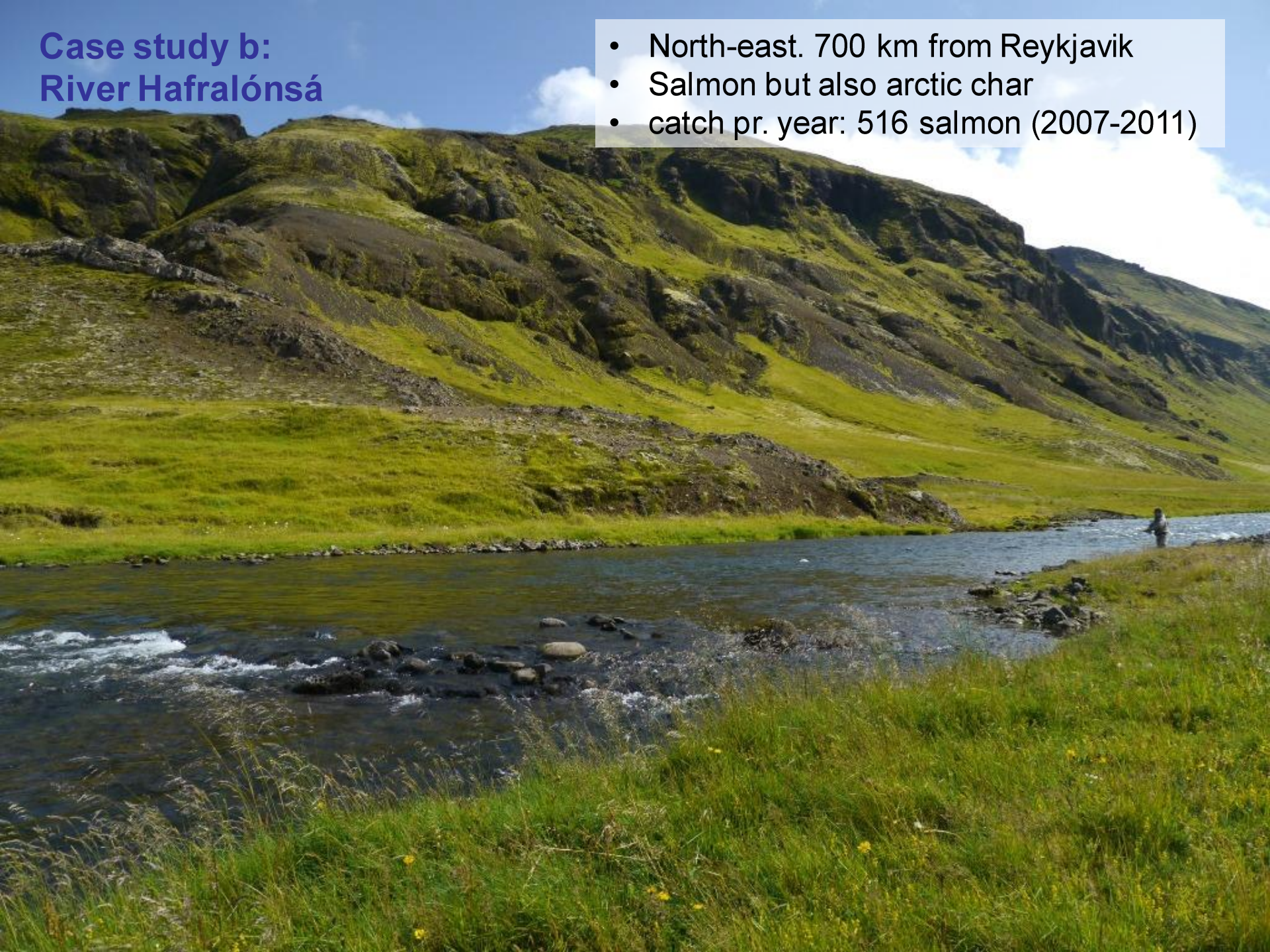
Switzerland: Grande Dixence (2068 MW; 2000 GWh) → Peak power

# How to assess Runoff?

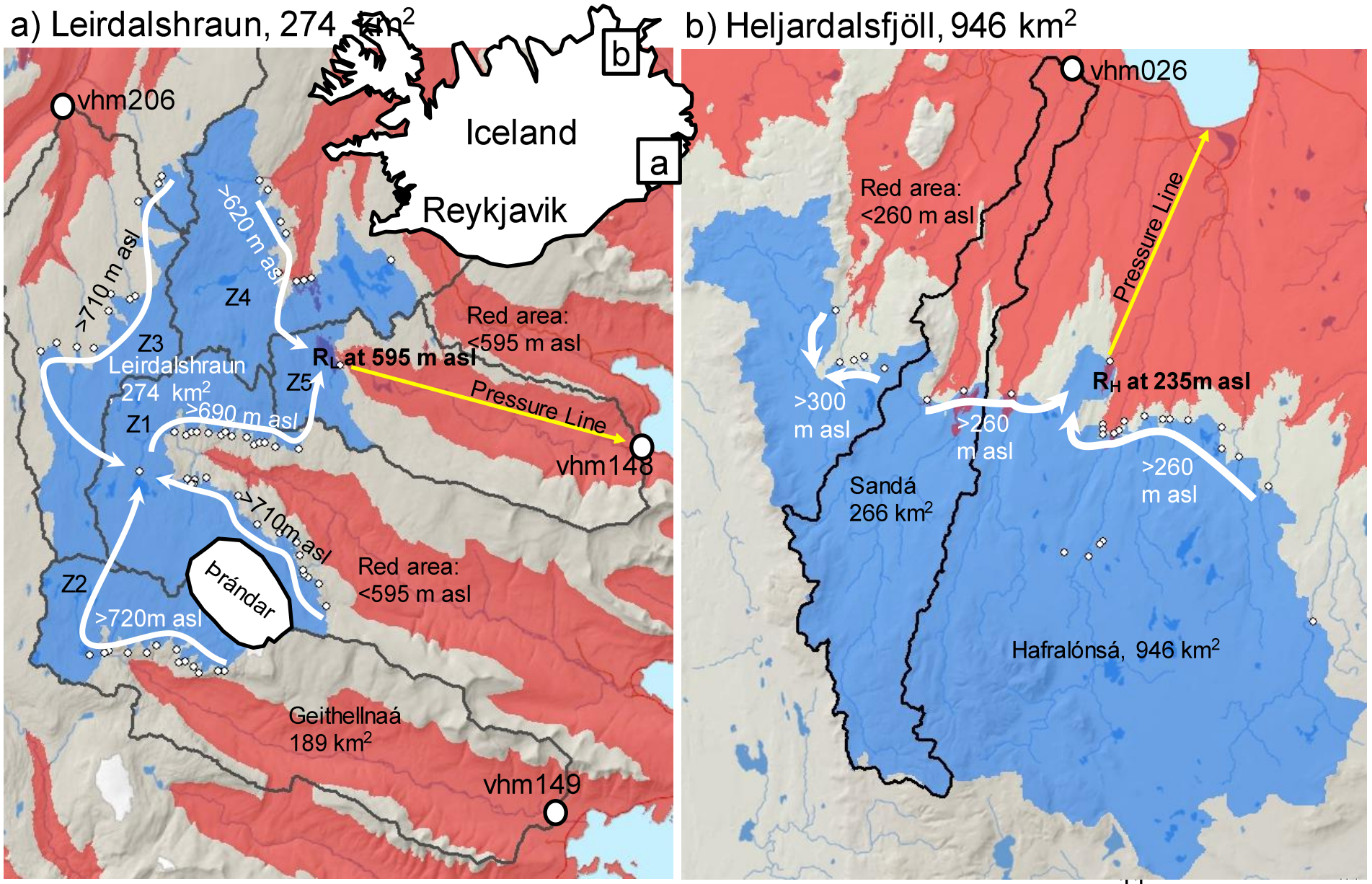

http://northlightpictures.com

# Case study b: River Hafralónsá

- North-east. 700 km from Reykjavik
- Salmon but also arctic char
- catch pr. year: 516 salmon (2007-2011)

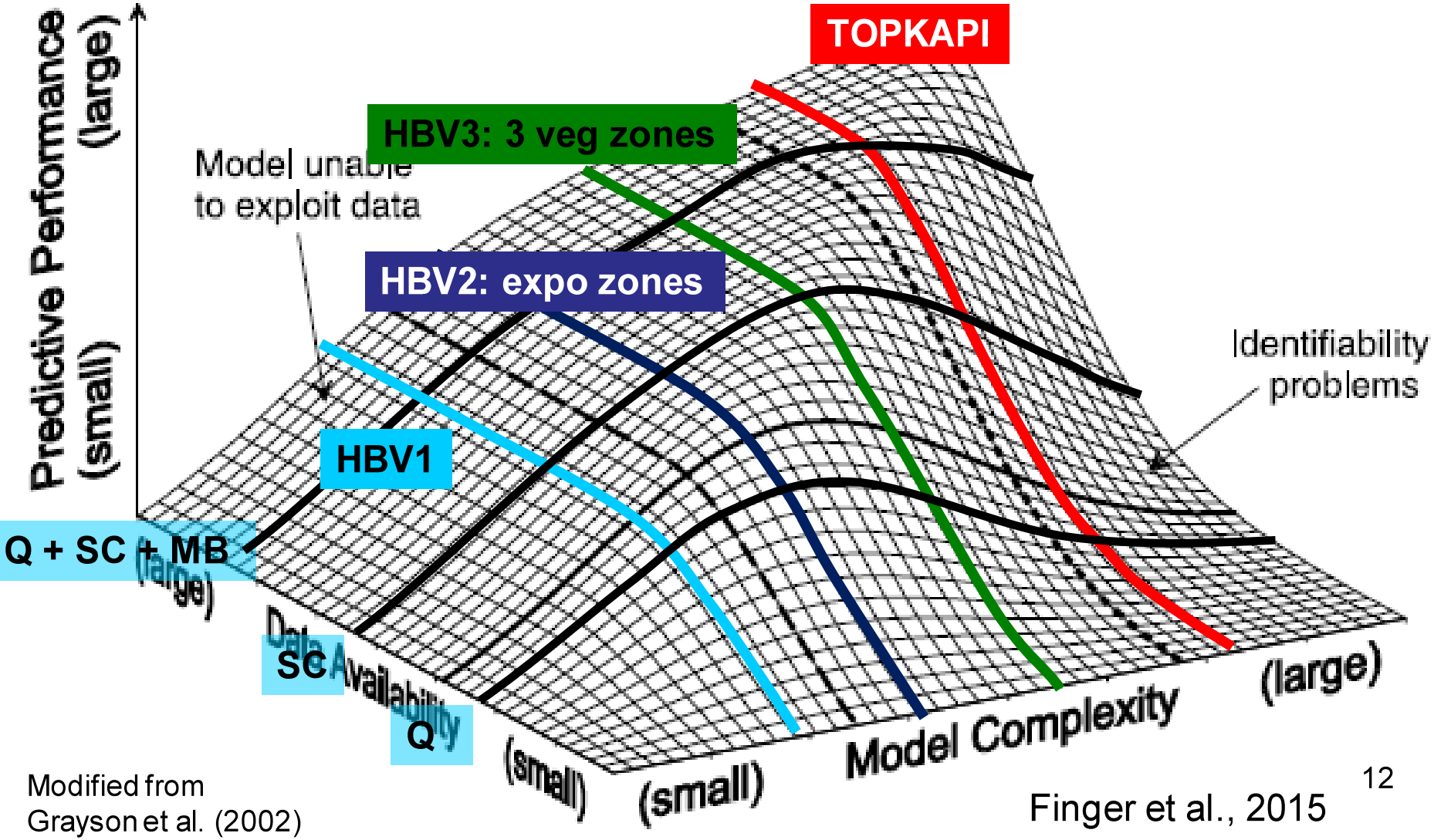


# Hydropower potential in Iceland



# Multi Data Set Calibration method: see Finger et al. 2011, 2015, WRR

Q: discharge
SC: Snow Cover
MB: Glacier mass balance

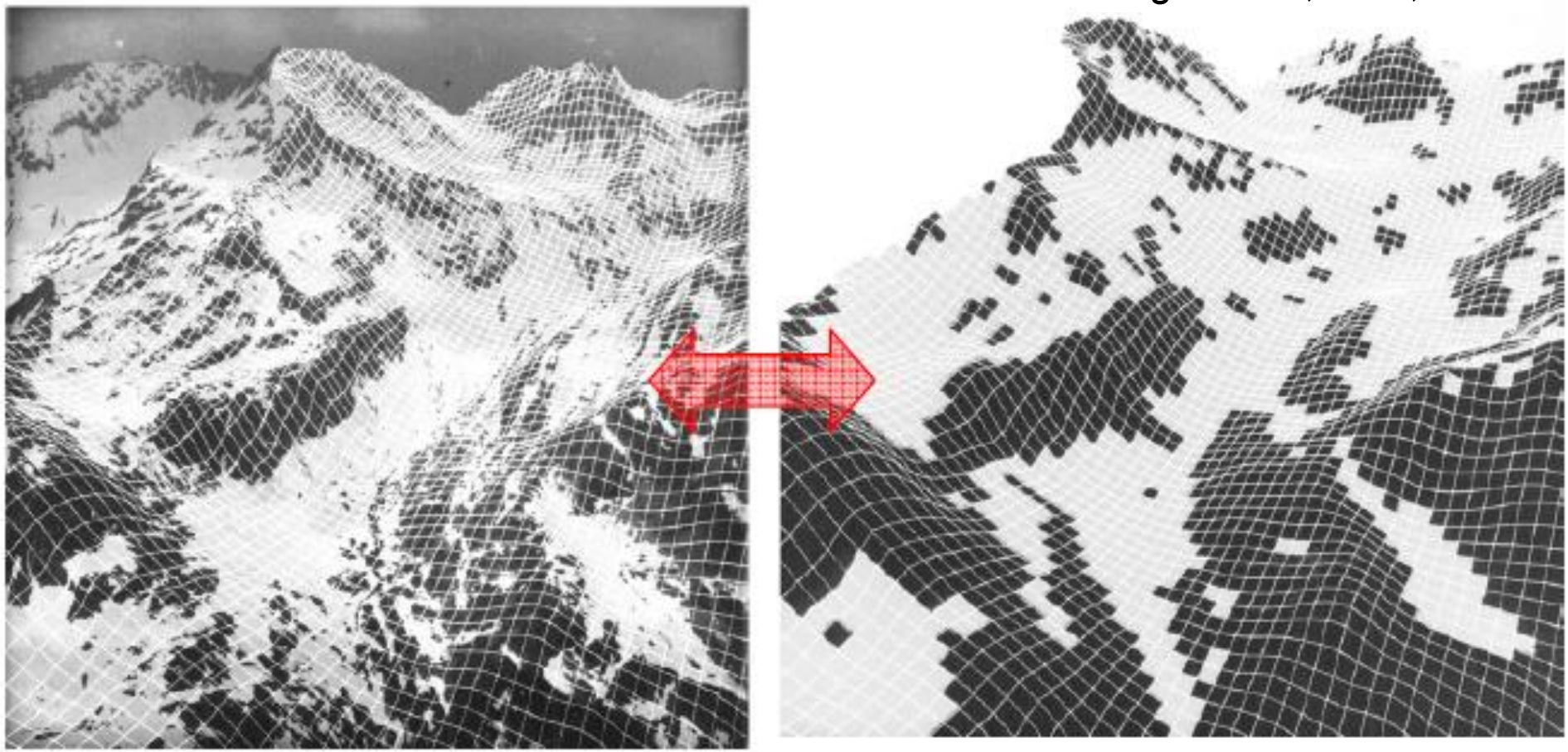



Modified from
Grayson et al. (2002)

Finger et al., 2015

# Calibration with MODIS satellite snow cover images

Finger et al., 2011, 2015



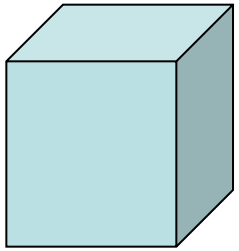
Efficinecy for distributed models (Finger et al. 2011):

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

Efficinecy for lumbed models (Finger et al. 2015):

$$E_{SC} = \frac{1}{n}\sum_{i=1}^{n}\left|1 - \left|a_{sim,i} - a_{obs,i}\right|\right|$$

# Stochastic Calibration: Monte Carlo Simulations



1. Run 10'000 plausible parameter sets

2. Assessment of performance

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

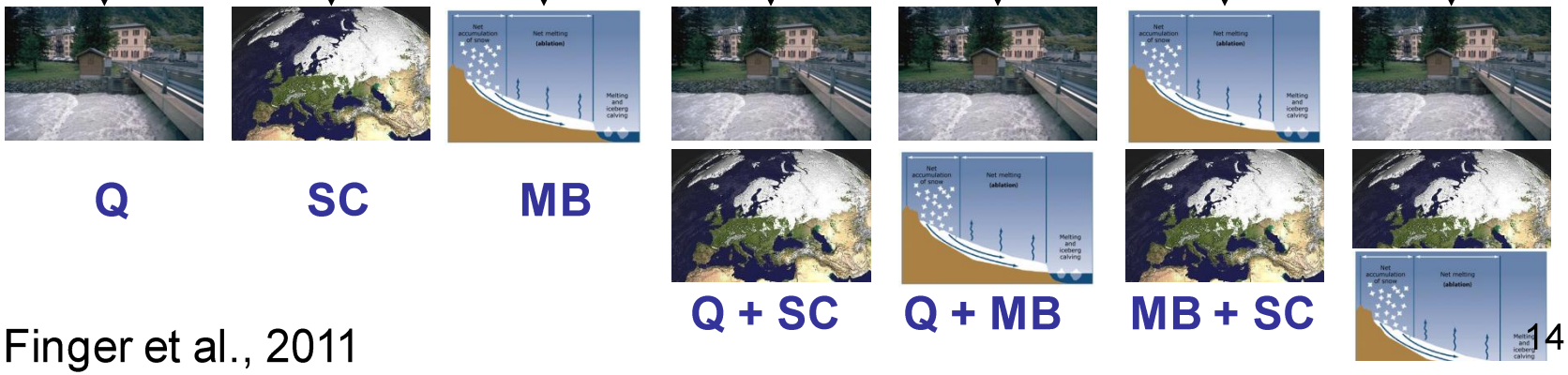
$$RMSE_{MB} = \sqrt{\sum_{j=1}^{m}\left(MB_{j,\mathrm{obs}} - MB_{j,\mathrm{sim}}\right)^2}$$

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

3. Ranking of parameter sets according to the 3 criteria

4. Determination of the ranking value
5. Overall performance = average of $P^i_r$

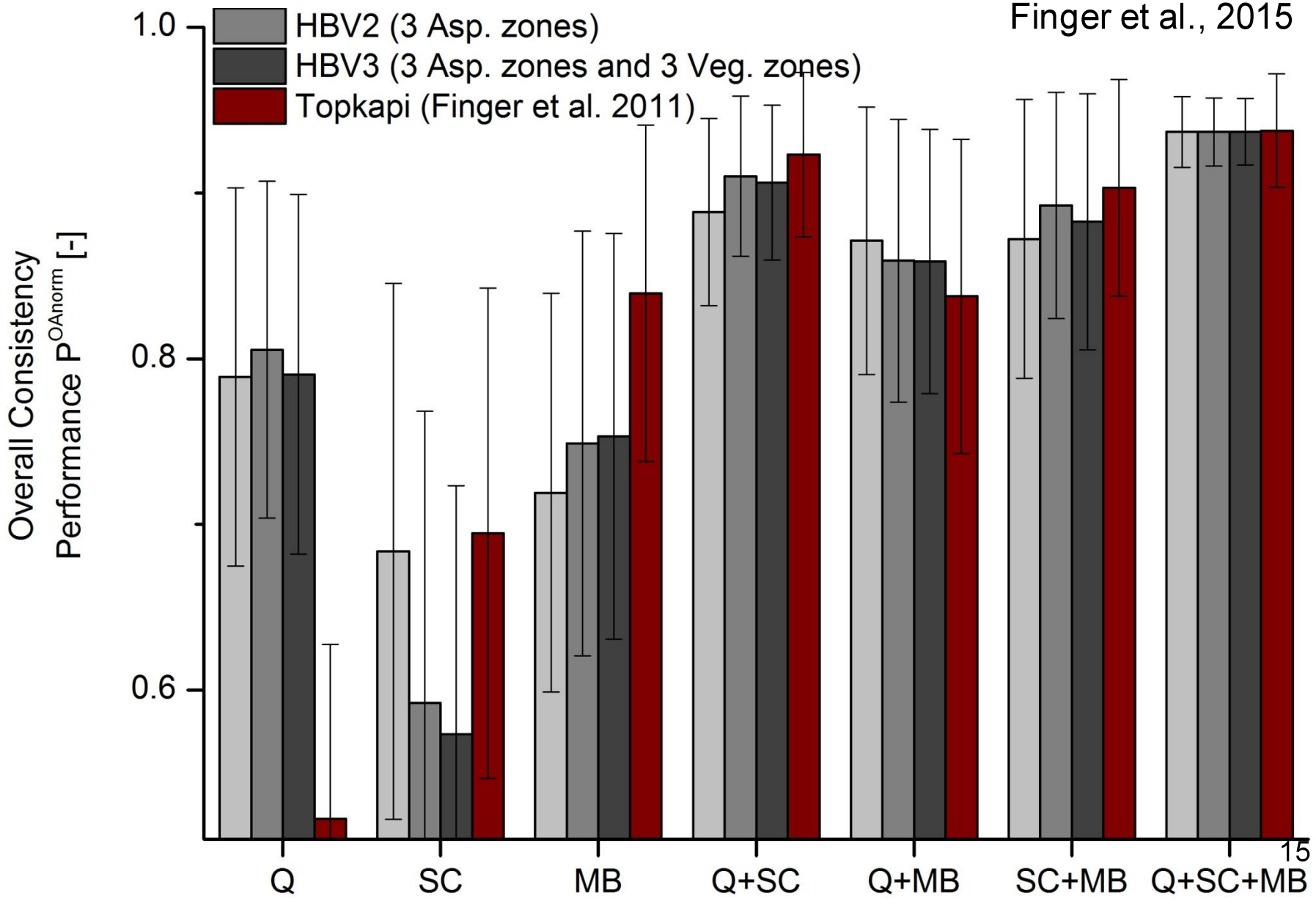
$$P_r^i = \frac{(N+1) - Rank_r^i}{N}$$



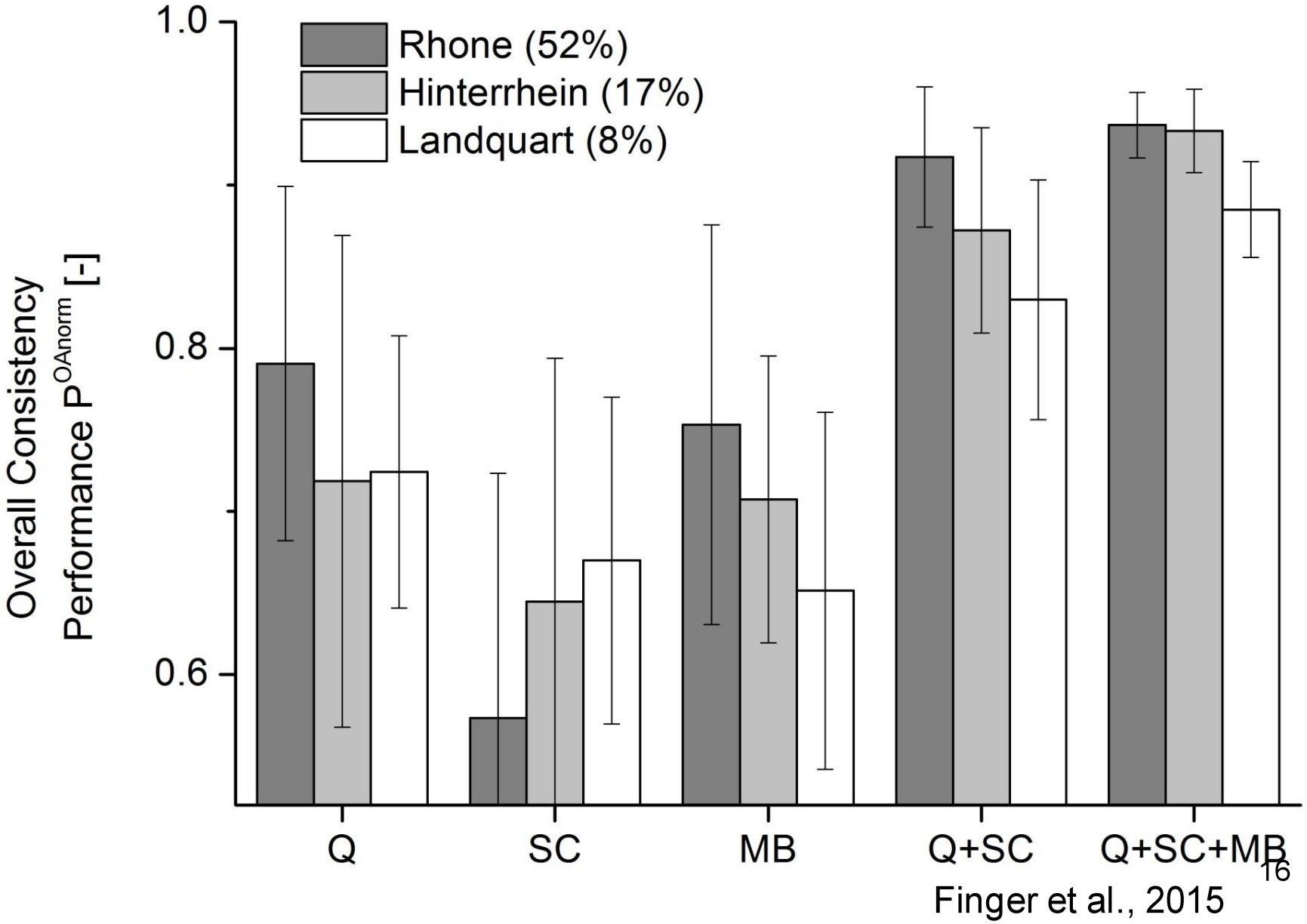
Q SC MB Q + SC Q + MB MB + SC Q + MB + SC

Finger et al., 2011

# Overall consistency performance of models with increasing complexity



# Overall consistency performance in study sites with decreasing glacierisation




Finger et al., 2015

# Trade-off between efficiencies

**Table 5.** Performance of Rhone Regarding Different Selection Criteria of the 100 Best MC-Runs During Calibration

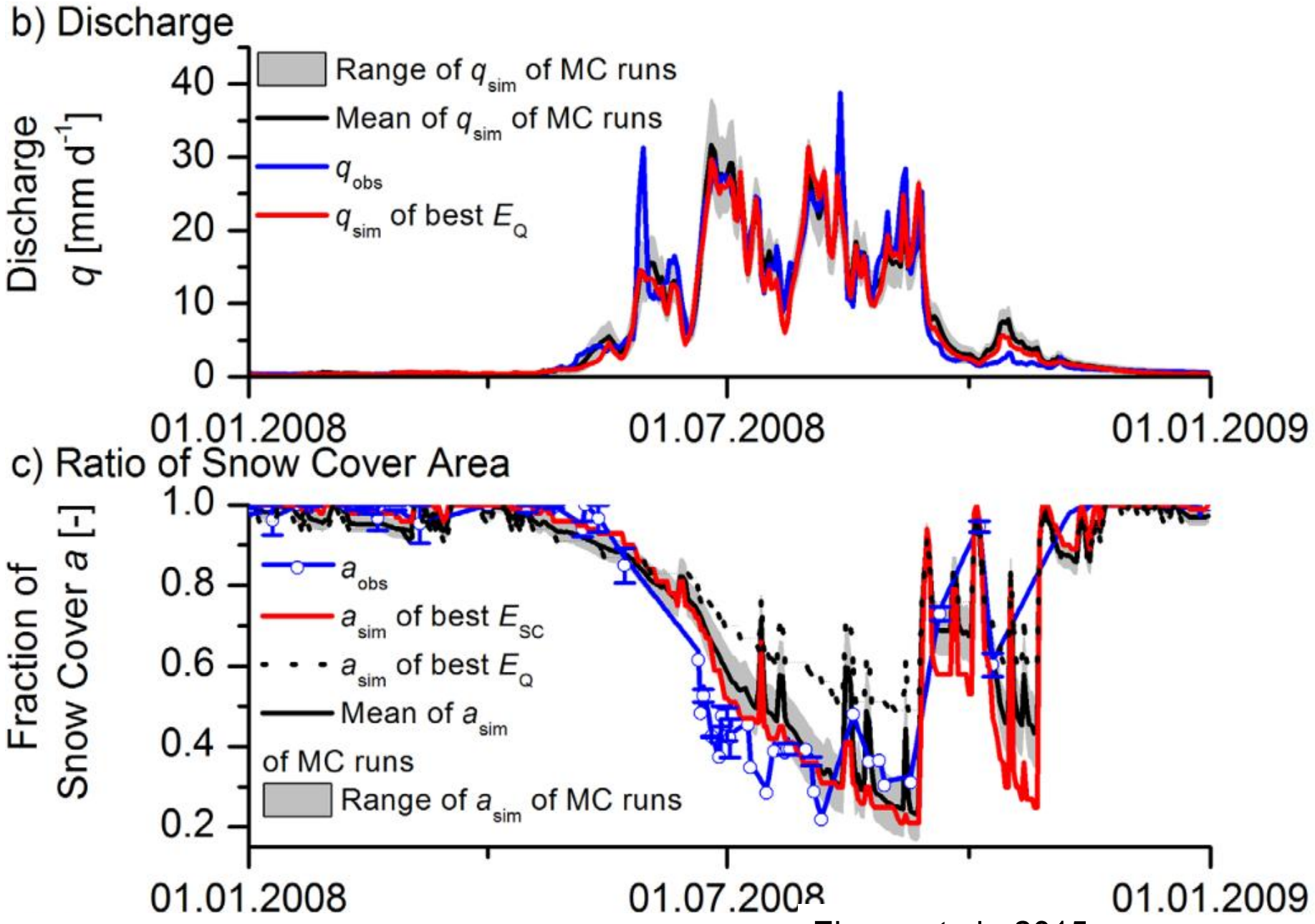
| | Performance Criteria | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Discharge $E_Q$ [-] | | Snow Cover $E_{SC,summer}$ [−] | | Mass Balances $E_{MB,abl}$ [mm w. eq.] | | Consistency Perf. $P^{OAnorm}$ [−] | |
| [a]Selection Criteria | Mean | Std | Mean | Std | Mean | Std | Mean | Std |
| Q | 0.912 | 0.006 | 0.879 | 0.026 | 1907.227 | 1007.419 | 0.791 | 0.109 |
| SC | 1.961 | 3.223 | 0.925 | 0.001 | 10002.875 | 6122.284 | 0.573 | 0.150 |
| MB | 0.782 | 0.087 | 0.873 | 0.033 | 486.965 | 115.472 | 0.753 | 0.122 |
| Q+SC | 0.889 | 0.019 | 0.915 | 0.005 | 1842.336 | 1021.465 | 0.906 | 0.047 |
| Q+MB | 0.895 | 0.015 | 0.890 | 0.020 | 893.392 | 215.205 | 0.859 | 0.080 |
| MB+SC | 0.807 | 0.122 | 0.916 | 0.005 | 950.524 | 287.872 | 0.883 | 0.077 |
| Q+SC+MB | 0.875 | 0.028 | 0.911 | 0.009 | 1225.856 | 498.622 | 0.937 | 0.020 |

[a]Shaded cells indicate that the data sets relevant for the criterion were used to select the best runs.



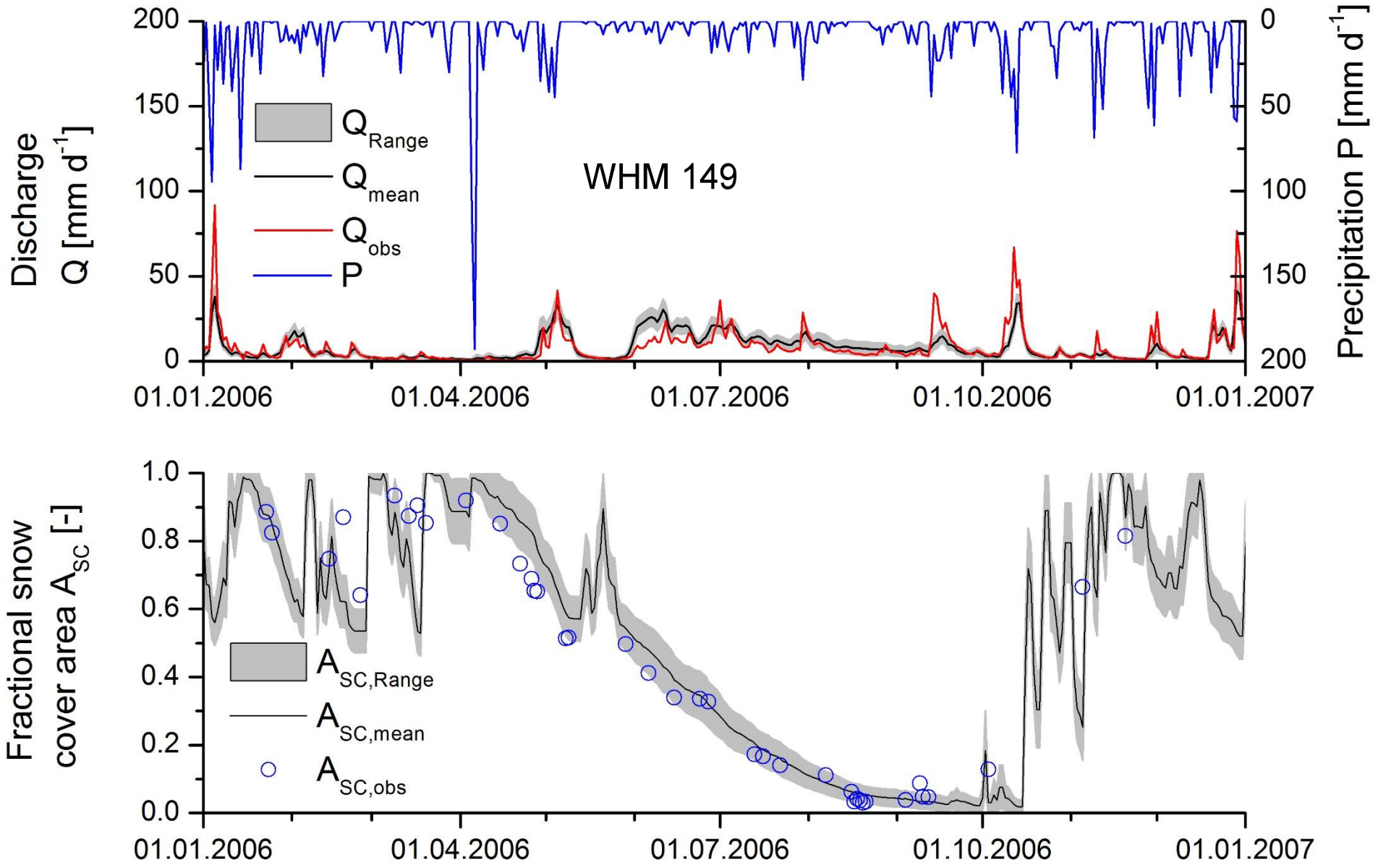
Finger et al., 2015

# Calibration using only Q and using SC and Q combined

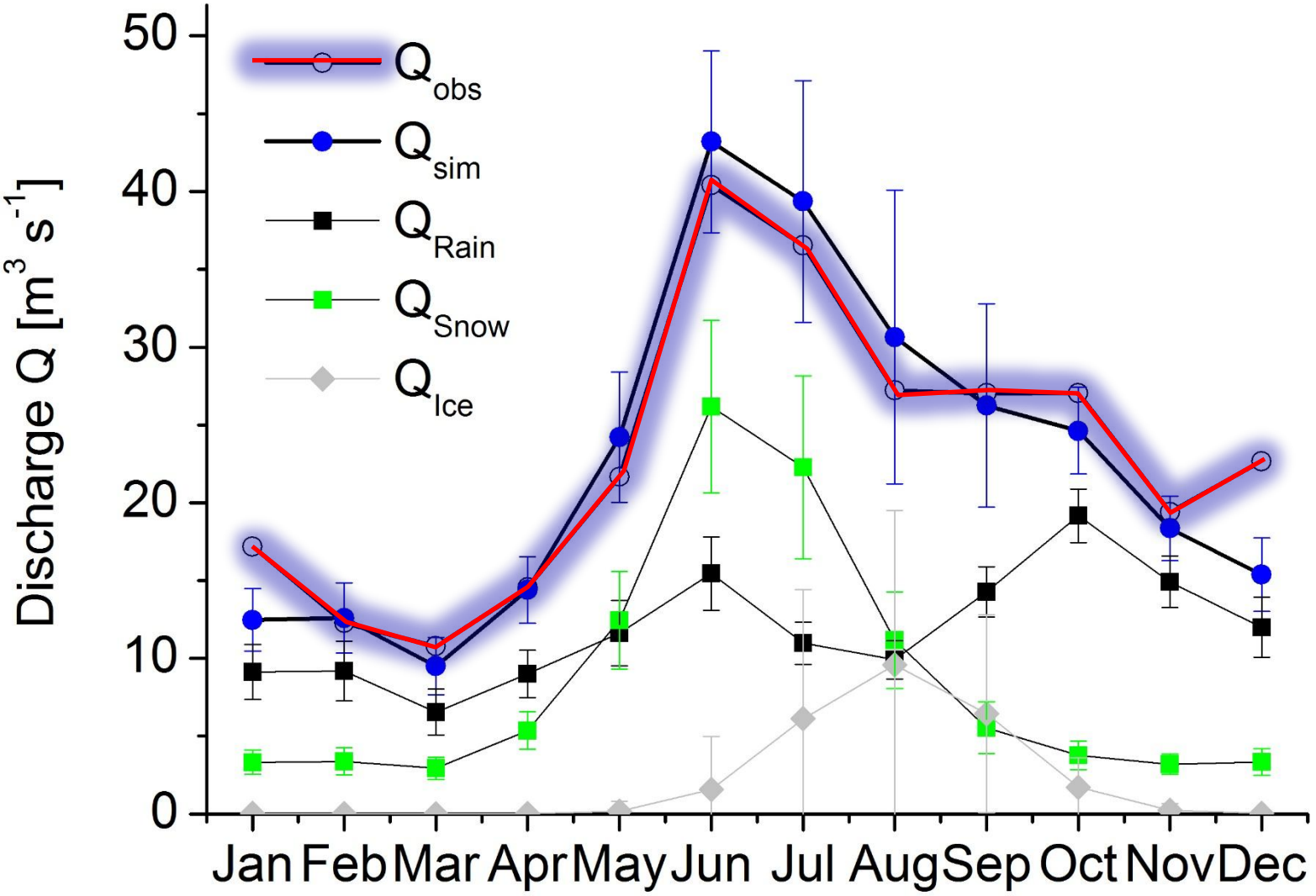



Finger et al., 2015

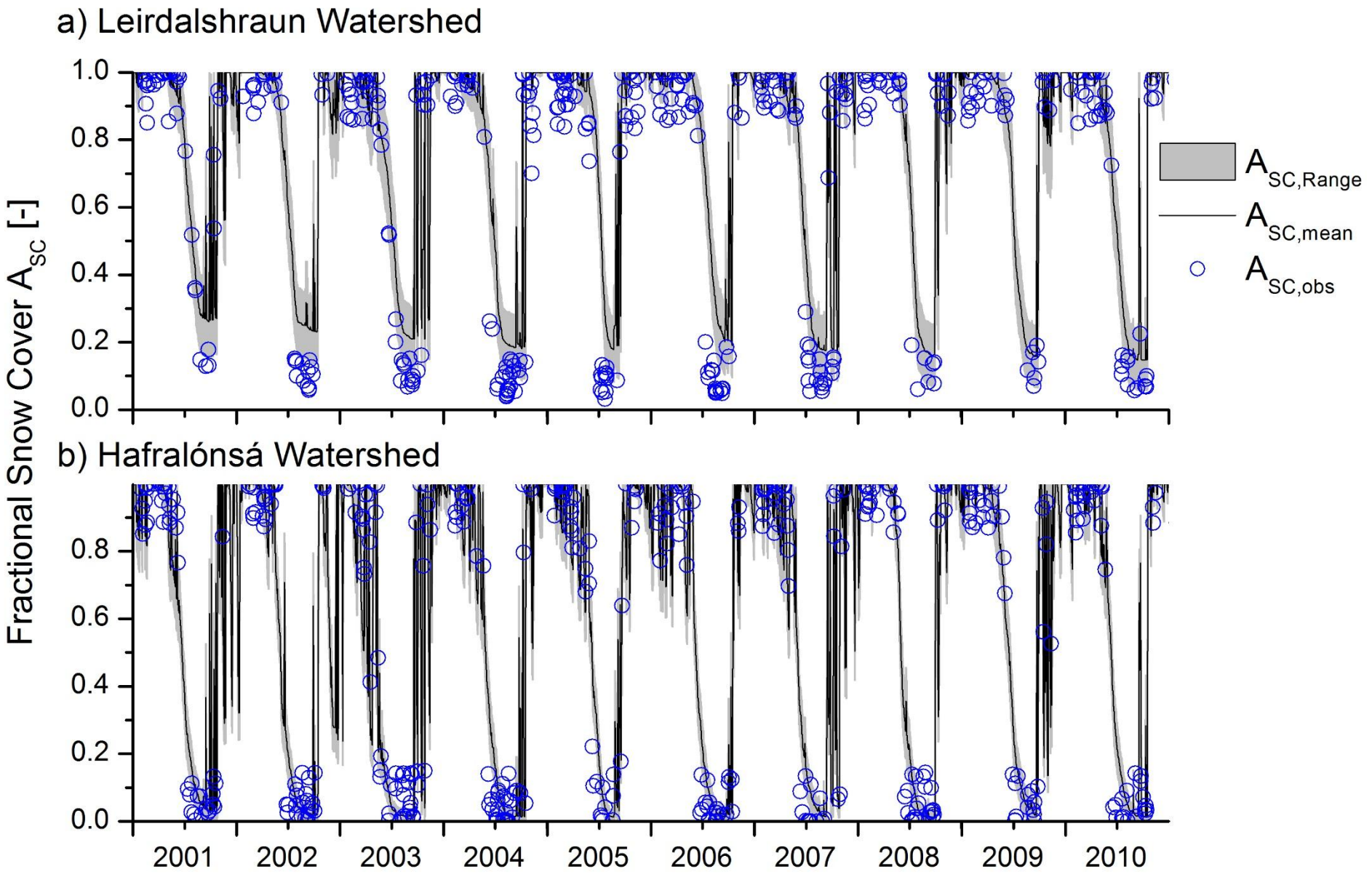
# Calibration runs for gauged sub-catchment in Iceland



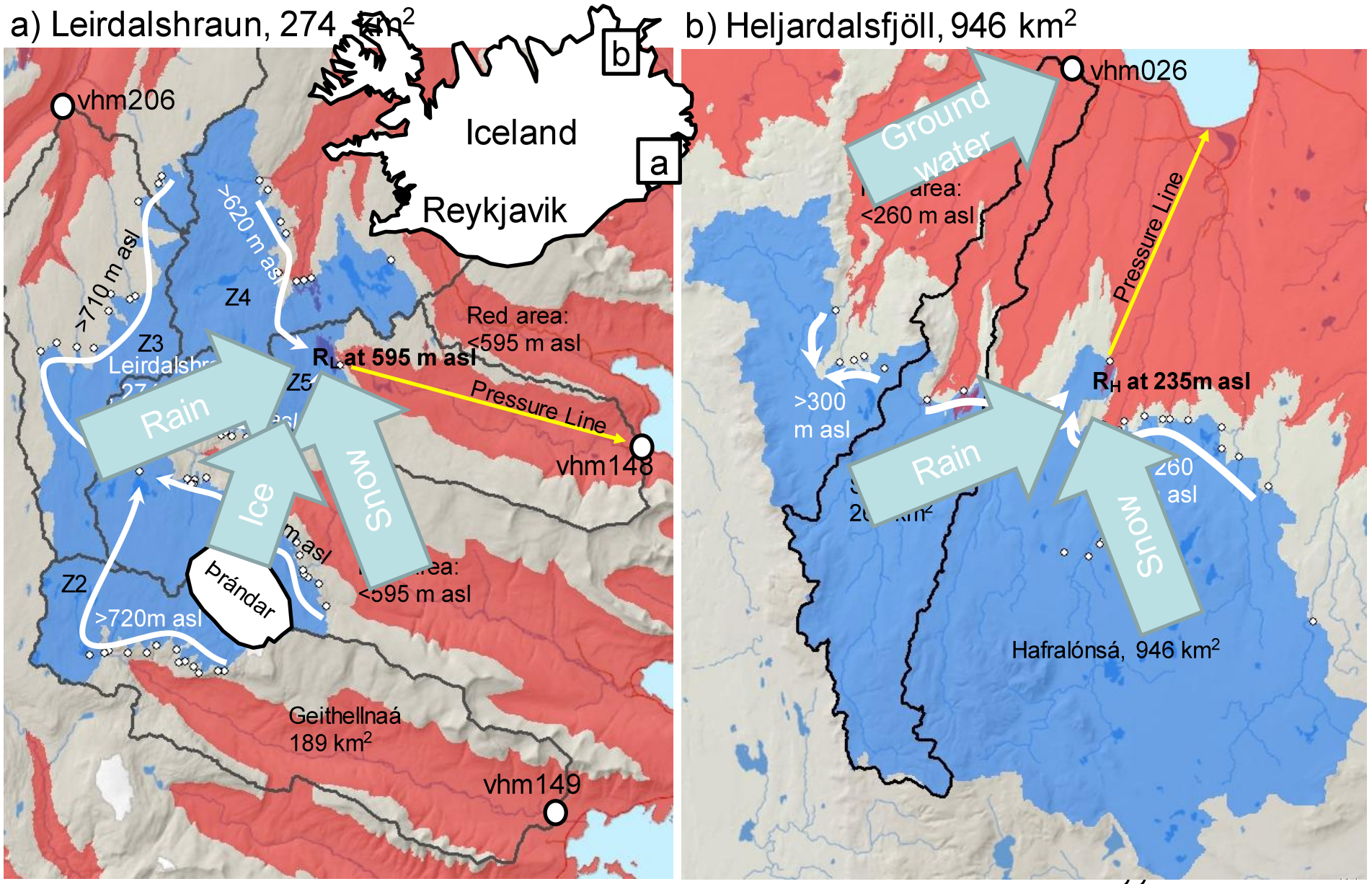
# Validation runs for gauged sub-catchment (vhm149) in eastern Iceland



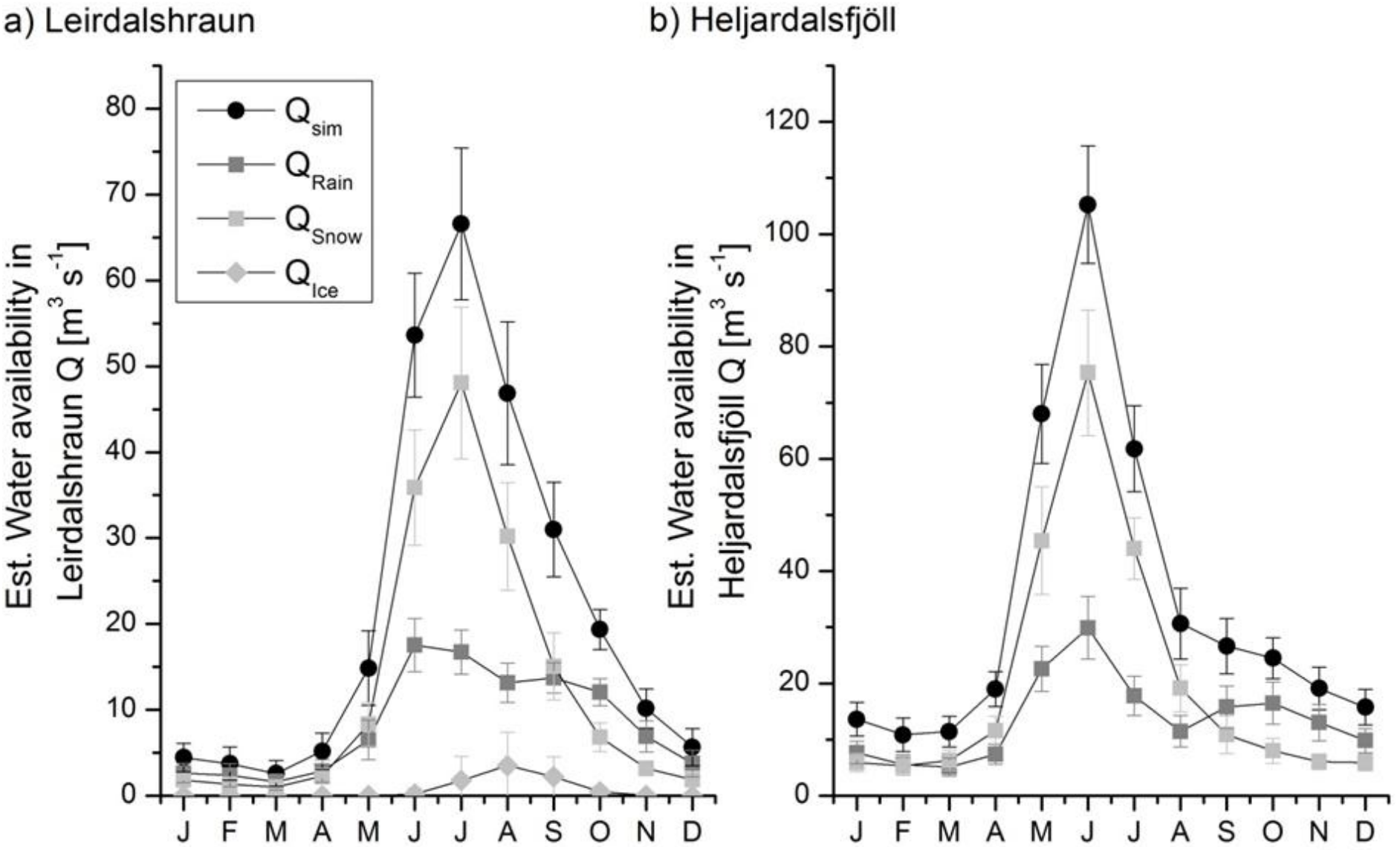
# Validation of snow cover for entire ungauged catchments



# Contribution to runoff can be constrained using SC



# Estimated water runoff in the ungauged areas

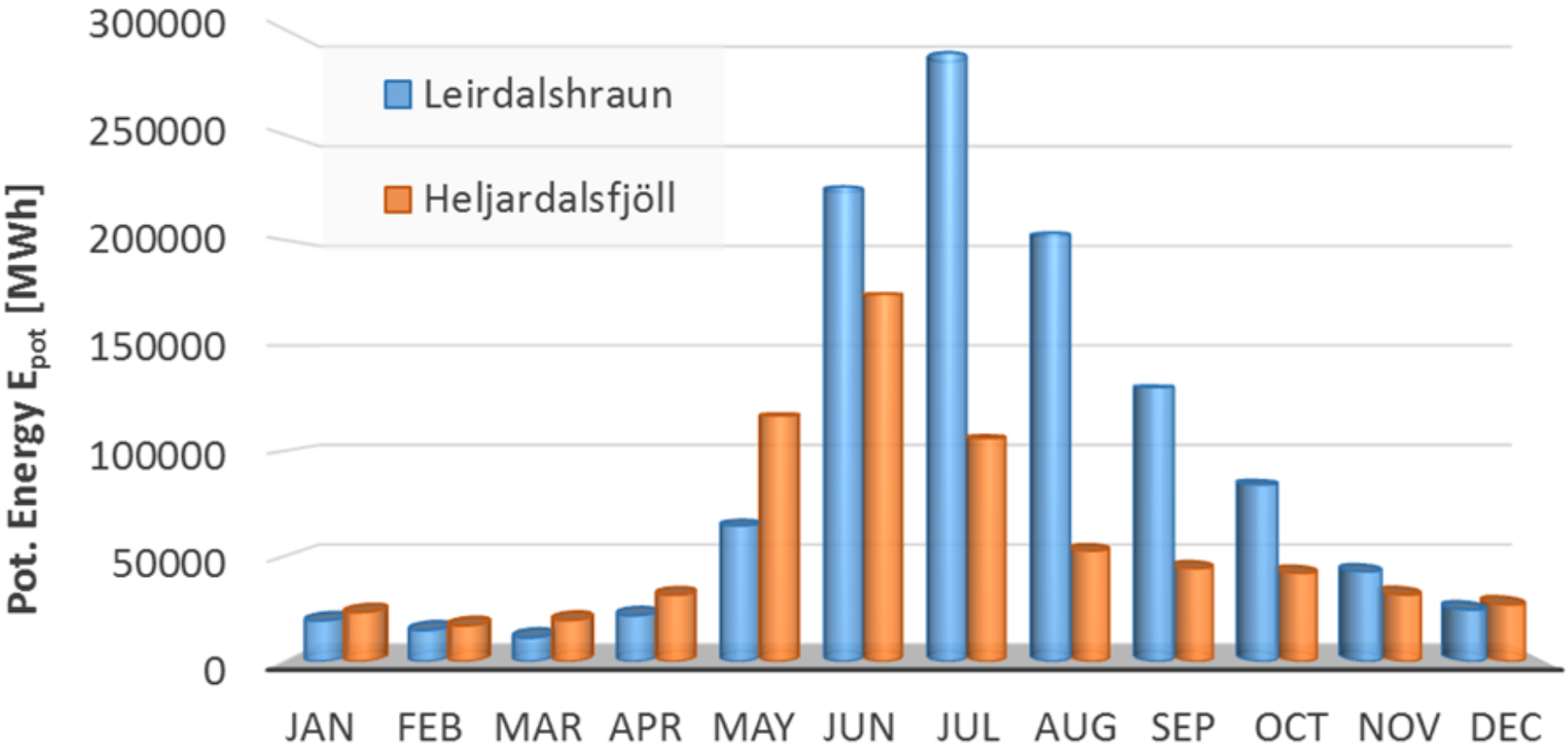



**Leirdalshraun: 274 km2; 595 m asl; 5.7 % glacierized → 792 GWh a$^{-1}$**

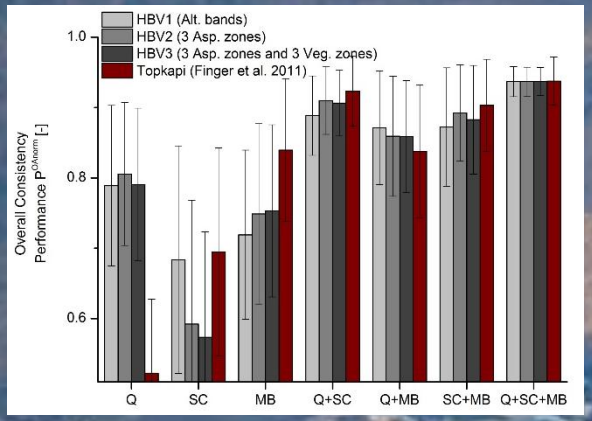
**Heljardalsfjöll: 946 km2; 235 m asl; → 480 GWh a$^{-1}$**

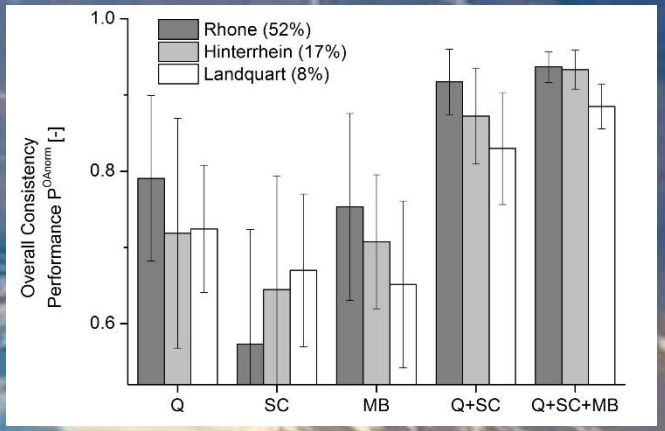
# Estimated hydropower potential in the ungauged areas

**Leirdalshraun: 274 km2; 595 m asl; 5.7 % glacierized**
**Heljardalsfjöll: 946 km2; 235 m asl;**



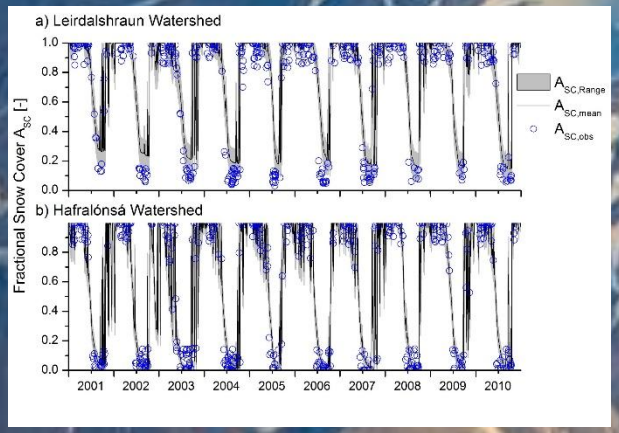
# Take home messages: MODIS snow cover data…

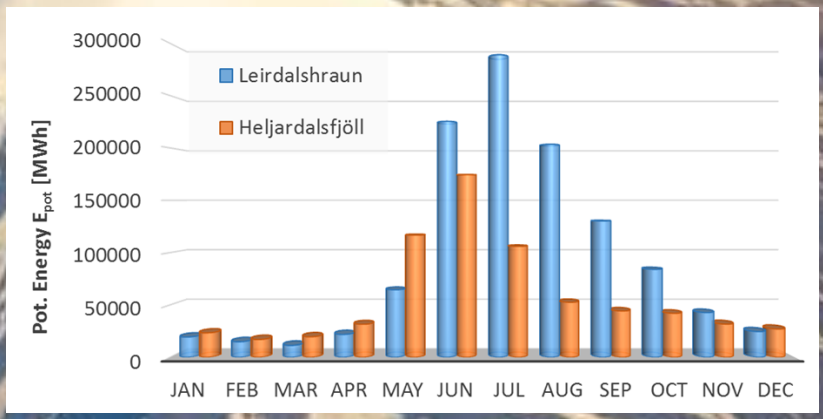



… improve hydrological simulations regardless of model complexity.

… has a bigger effect in areas with low glacierisation.




… allow validation of ungauged areas.

… allow an estimation of the hydropower potential.

# Þakkir fyrir athygli þína

Sjáumst á Íslandi
Summer school
registration open now!!!
https://fingerd.jimdo.com/teaching/

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