Trends in S and N budgets of Swiss high-altitude lakes

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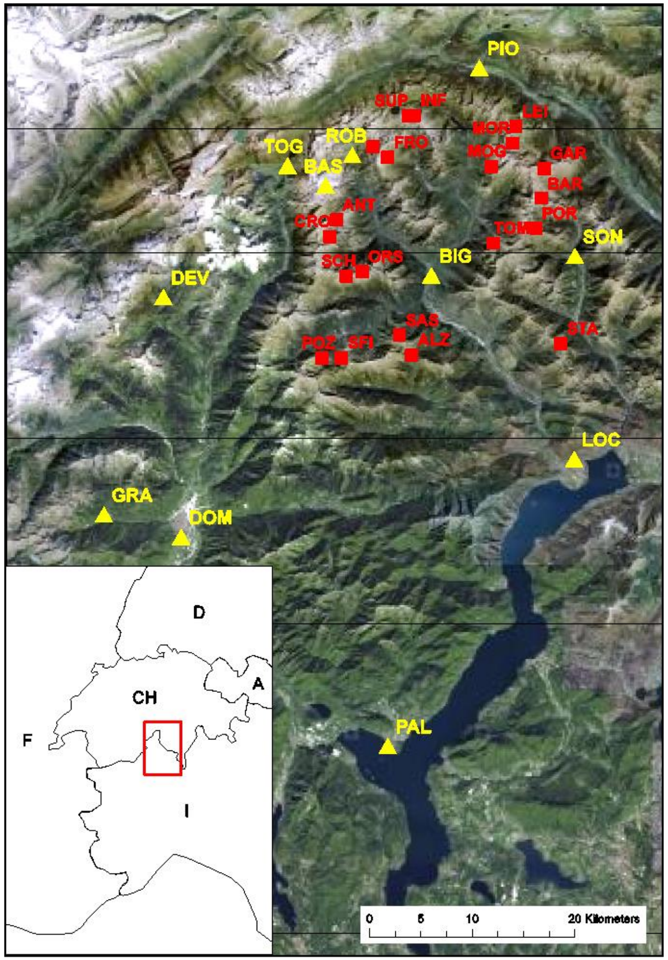
Study site



▲ wet-deposition sampling sites

CH: BAS, BIG, LOC, PIO, ROB, SON
I: DEV, DOM, GRA, PAL, TOG

■ 20 high-altitude alpine lakes

Catchment characteristics:

Altitude: 1970-2638 m a.s.l.

$Area_{lak}/Area_{catch}$: 0.01-0.18

Terrain slope: 43-58 %

Z/τ lake: 12-113 m yr^{-1}

Mean yearly precipitation (2000-2015): 1450-2400 mm

Mean N input (2000-2015): 10-15 kg N ha^{-1}

Mean S input (2000-2015): 4-6 kg S ha^{-1}

Introduction

- **Rainwater** concentration trends in Southern Switzerland1980's-2016 :

	SO4	NO3	NH4	BC	Gran Alk	H
Significant decreasing trends	9	7	5	5	0	8
Significant increasing trends	0	0	0	0	8	0
No significant trends	0	2	4	4	1	1

See also: Rogora et al. 2016, Atmos. Environ. 146: 44-54

- Concentration trends in **high-altitude lakes** in Southern Switzerland1980's-2016 :

	SO4	NO3	BC	Gran Alk	H
Significant decreasing trends	15	17	14	0	15
Significant increasing trends	3	0	2	17	0
No significant trends	2	3	4	3	5

See also: Rogora et al. 2013, Water Air Soil Pollut. 224: 1746

- But what happens in the catchment?

Methods

- Yearly Input-Output budgets for S, N and BC for each lake during 1980's-2015

- **Total input** = wet deposition + dry deposition

    wet deposition = Conc * Prec

    concentrations in wet deposition -> time dependent altitude gradient derived from sampling sites above 900 m a.s.l.

    precipitation: modelled for CH by Meteotest based on MeteoSwiss data (1 km x1km)

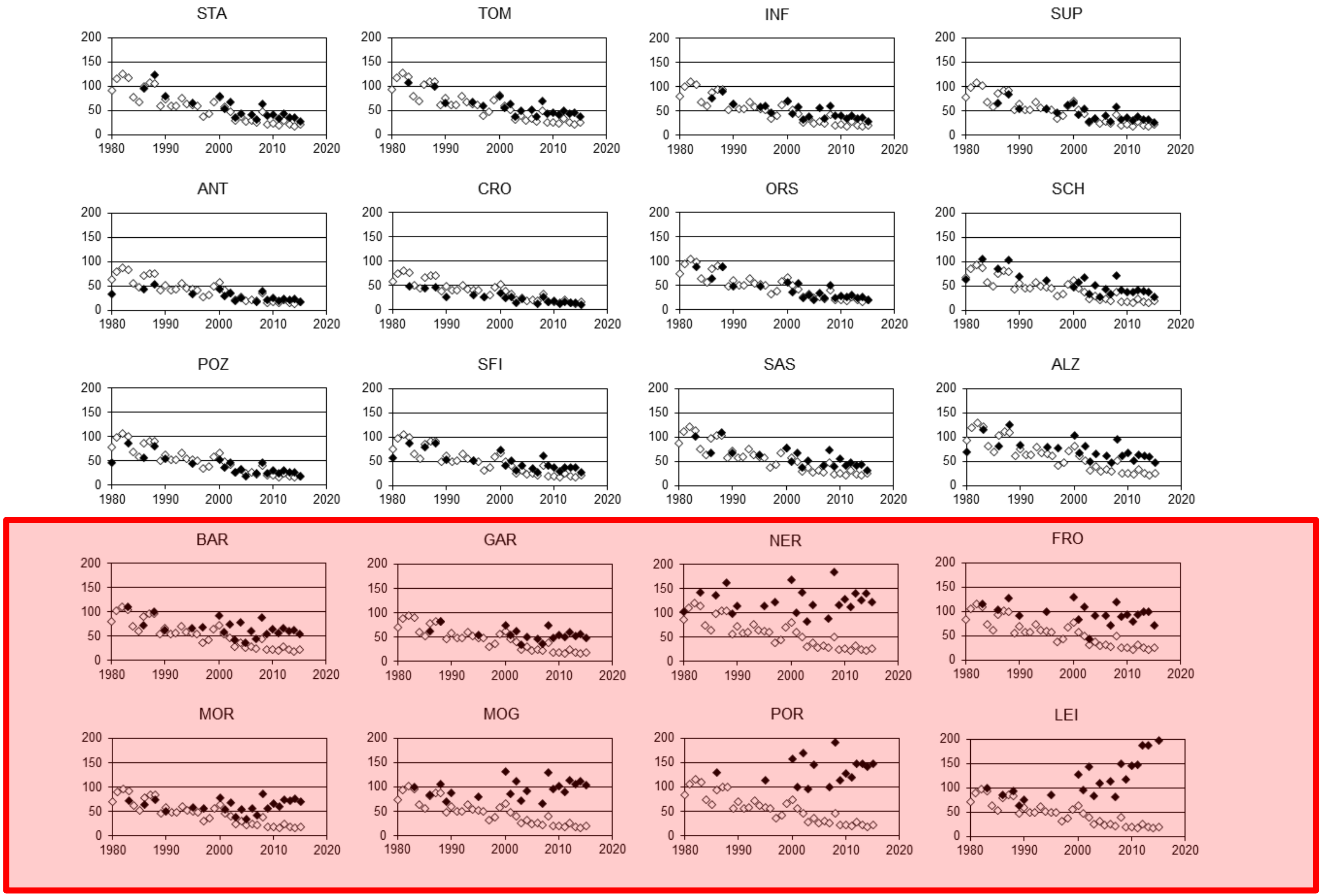
    dry deposition -> modelled for CH by Meteotest (1 km x1km)

- **Output** = average lake autumn surface Conc * (Prec – ET)

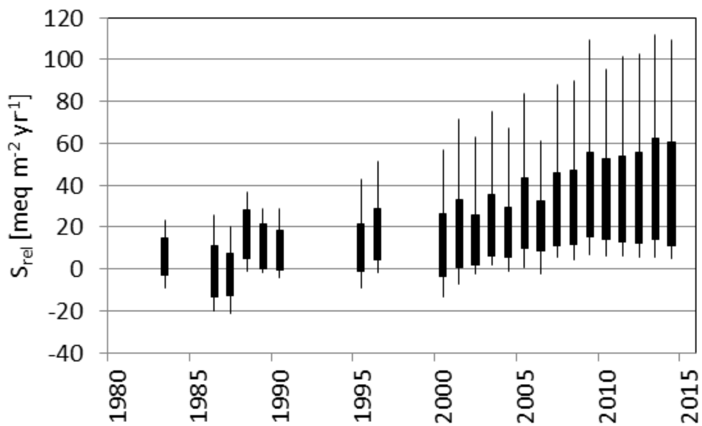
    $ET = Prec * E_{1973\text{-}1992}/P_{1971\text{-}1990}$

- Yearly **retention/release** calculated as difference between 3-years moving means of input and output -> to reduce temporal variablity

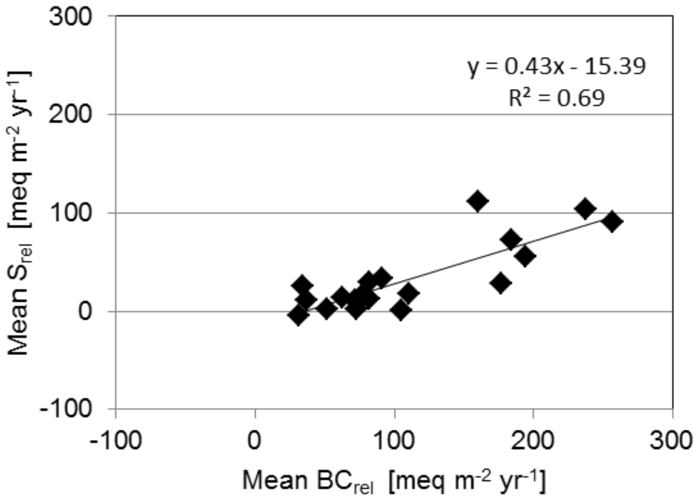
S input (white diamond) and S output (black diamond) expressed in meq m^{-2} yr^{-1}

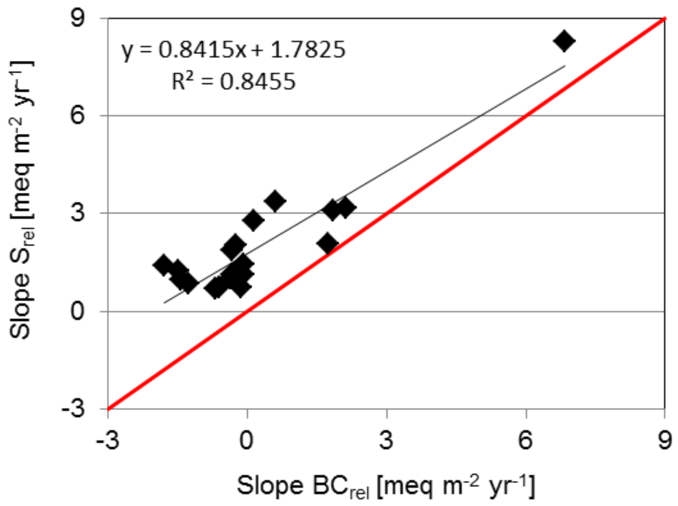


Percentiles (10%, 25%, 75%, 90%) of the release (S_{rel})

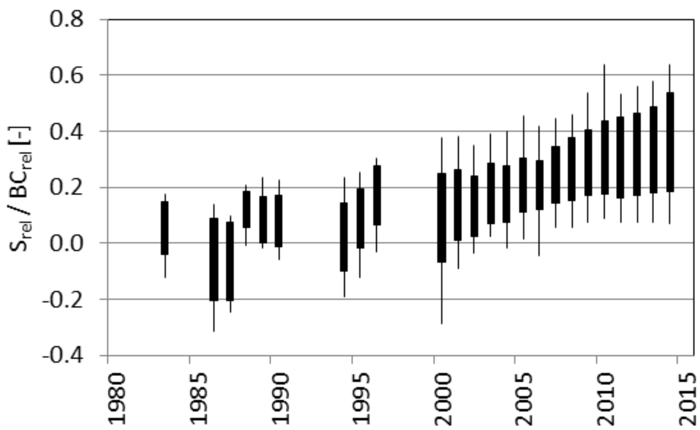


Correlations between S_{rel} and BC_{rel} for 2000-2015

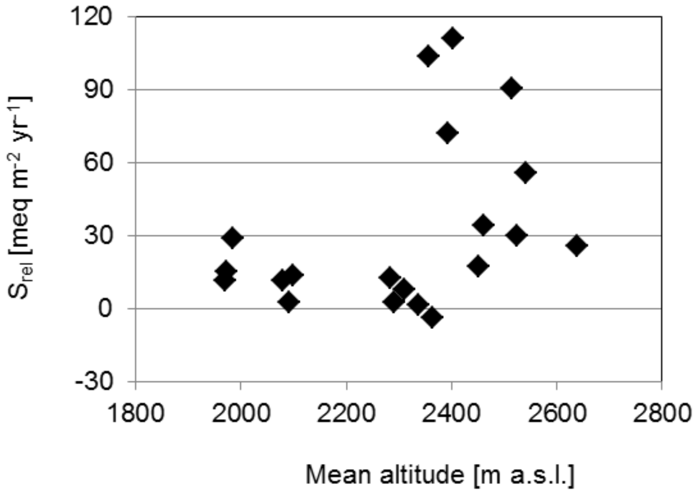


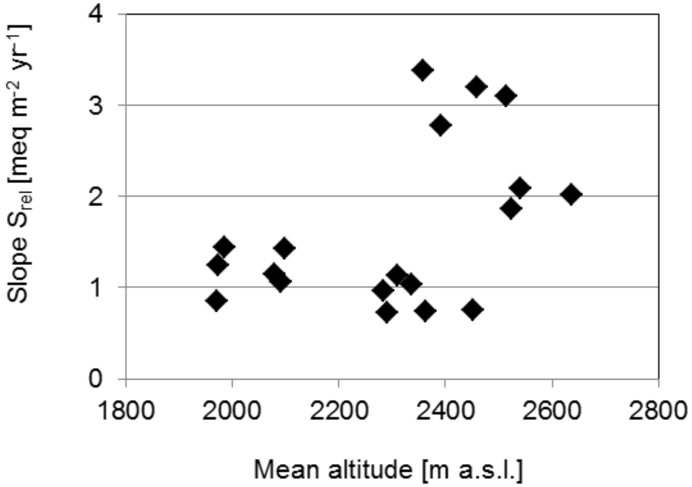


Temporal change of S_{rel} and BC_{rel} ratio



Correlations between S_{rel} and altitude for 2000-2015





Occurrence of permafrost in the Alps

Relative abundance of permafrost in lake catchments is not known

However, for the the entire Alps the likelihood of permafrost occurrence has been modelled->

APIM = Alpine Permafrost Index Map (data publicly available)

Index: 0-1

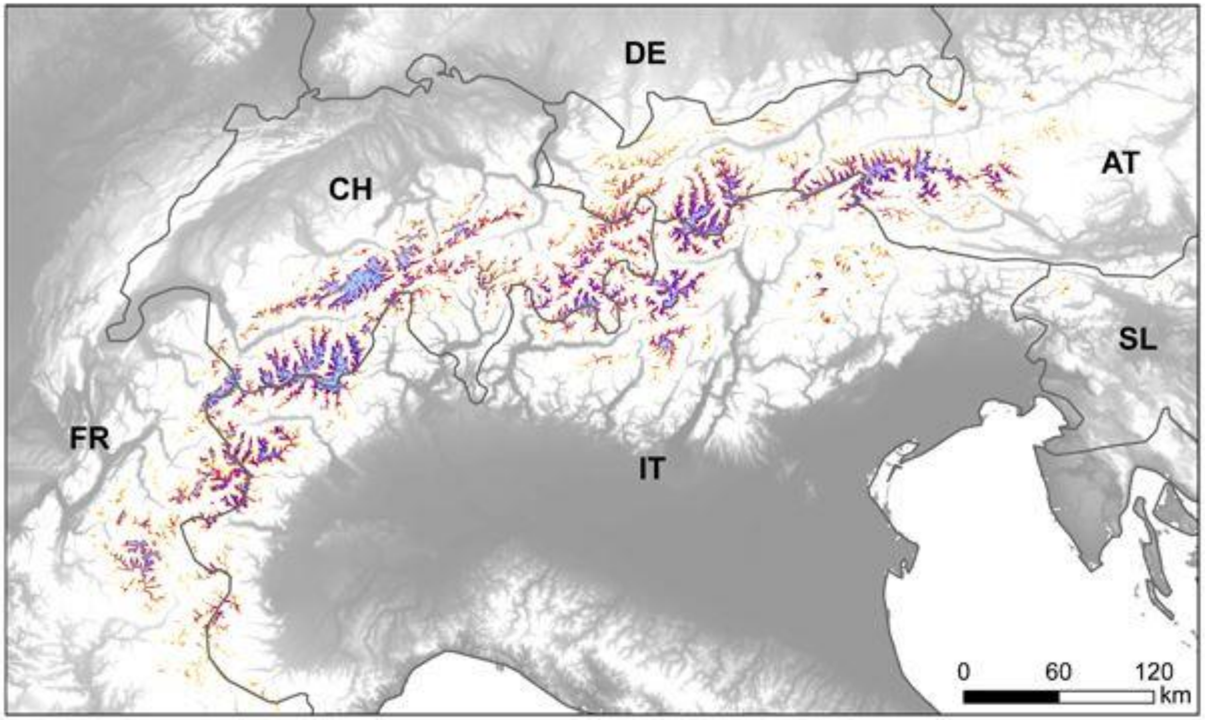
Based on mean annual temperatures, potential incoming solar radiation, precipitation

Source:
http://www.geo.uzh.ch/microsite/cryodata/PF_map_explanation.html

References:

Boeckli, L., Brenning, A., Gruber, S. & Noetzli, J. (2012): Permafrost distribution in the European Alps: calculation and evaluation of an index map and summary statistics. The Cryosphere, 6, 807–820

Alpine Permafrost Index Map (APIM)



Source: https://www.geo.uzh.ch/microsite/cryodata/PF_map_explanation.html

Alpine Permafrost Index Map (APIM): Interpretation key

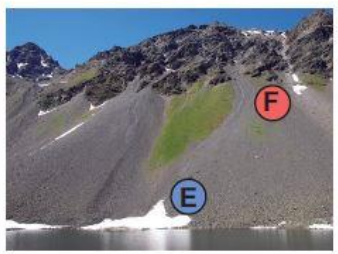
Interpretation Key

Clast size, soil properties and vegetation

A cover of coarse blocks with open voids and no infill of fine material (A) indicates cold conditions. Bedrock, fine-grained soil or soil with coarse blocks but an infill of fines (B) indicate warm conditions. A dense vegetation cover (C) usually indicates the absence of permafrost.

Rock glaciers

Active (intact) rock glaciers (D) are identified by signs of movement such as steep fronts. They are reliable visual indicators of permafrost within their creeping mass of debris but do not allow easy conclusions on adjacent areas.



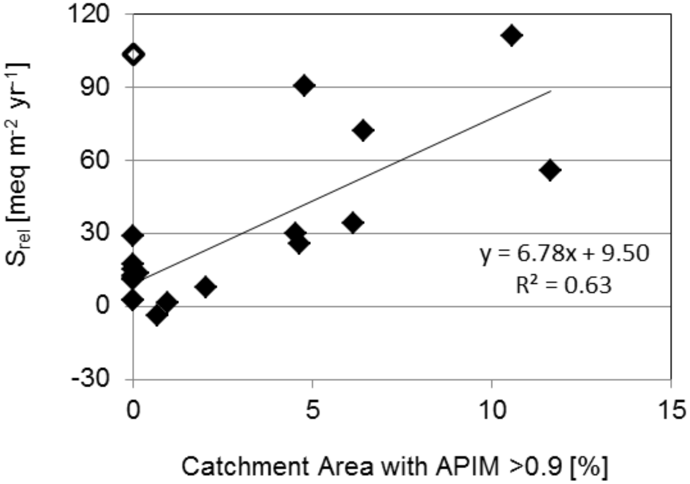
Slope position and long-lasting snow-patches

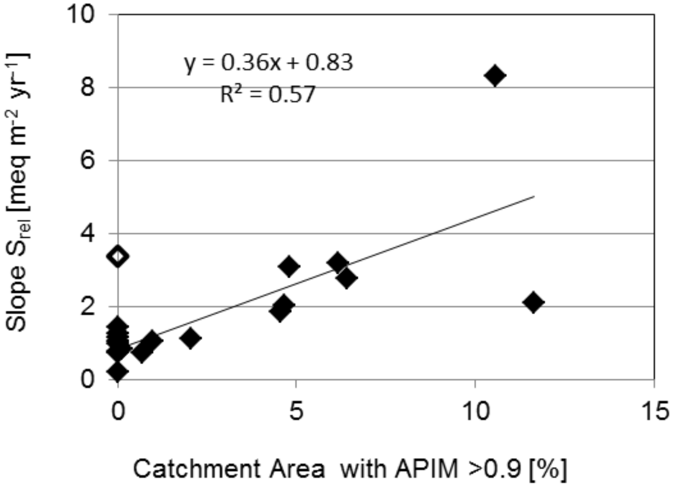
The position along a slope can affect ground temperatures through the sorting of clasts, air circulation within the slope, and snow re-distribution. Often, the foot of slope (E) has colder ground temperatures. It contains more coarse material and is affected by long-lasting avalanche snow. Similarly, other late-lying snow patches indicate locally cold conditions. The top of slope (F) often has locally rather warm conditions. Frequently, it contains smaller clasts as well as an infill of fine material.

Steep rock slopes

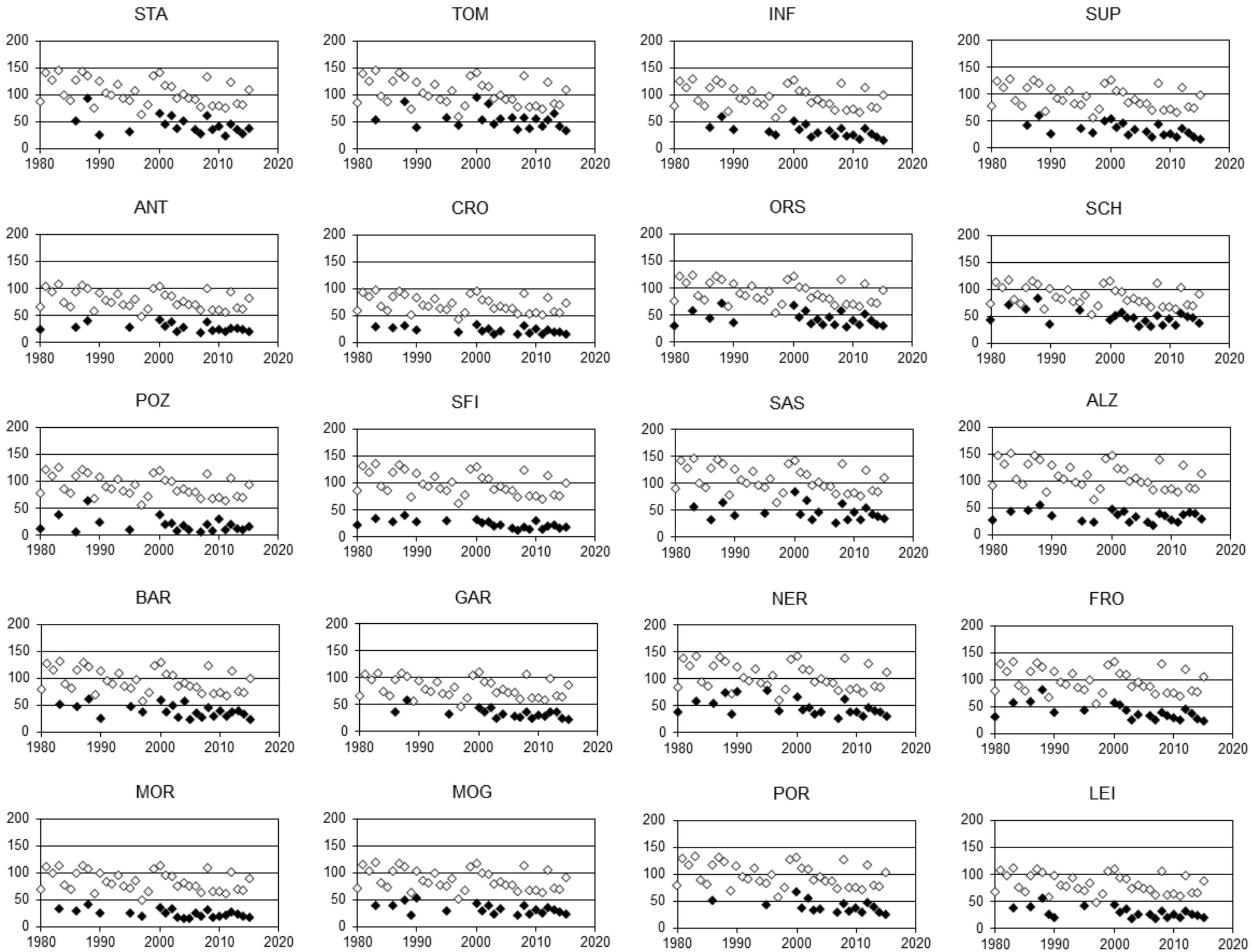
Steep rock slopes have differing degrees of heterogeneity caused by micro-topography and fracturing. Higher heterogeneity (G) often enables a thin snow cover as well as ventilation and deposition of snow in large fractures, indicating locally cold conditions. Steep, smooth and largely unfractured rock (H) is indicative of warmer conditions. This effect is more pronounced in sun-exposed than in shaded locations.

Correlations between S_{rel} and the relative catchment surface with APIM>0.9

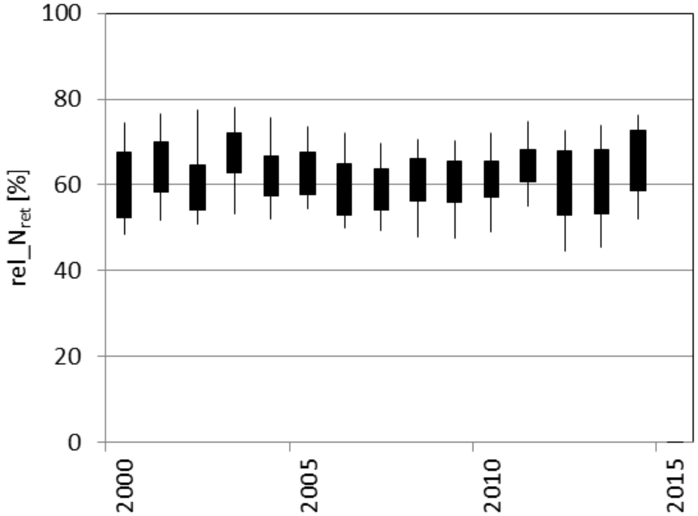




N input (white diamond) and N output (black diamond) expressed in meq m^{-2} yr^{-1}



Percentiles (10%, 25%, 75%, 90%) of the relative N retention (rel_N_{ret})

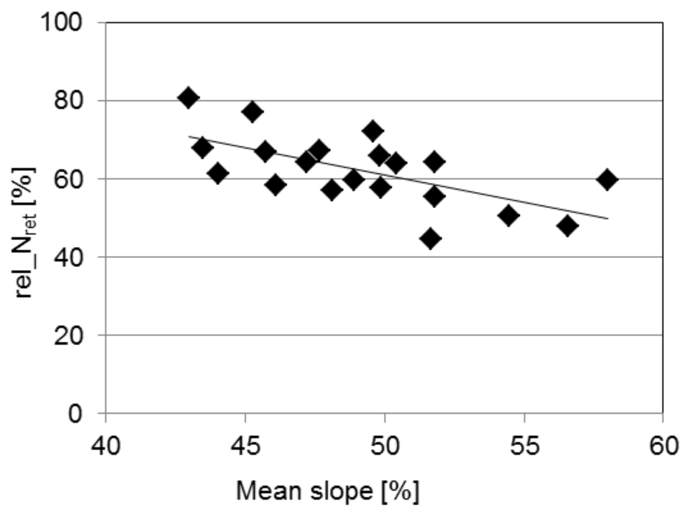


- Relative retention of N fairly constant
- Mean=62%
- Great variability among lake catchments: N_{ret} mean 2000-2015 from 45% to 81%
- What determines variablity in N_{ret}?

Pearson correlation between rel_N_{ret} and environmental variables

Variables	Rel_Nret [%]
Mean altitude [m a.s.l.]	-0.122
Area [ha]	-0.084
Mean precipitation [m]	-0.356
$Vegetation_{Geostat}$ [%]	0.304
$Vegetation_{Geostat}$ + Lake [%]	0.327
$Vegetation_{Boeckli\ et\ al.\ 2012}$ [%]	0.388
$Vegetation_{Boeckli\ et\ al.\ 2012}$ + Lake [%]	0.412
Mean lake areal outflow= Z_{lak} / τ [m yr^{-1}]	-0.493
Mean Slope [-]	-0.629

Correlation of N_{ret} with mean catchment slope



How much nitrogen is retained in the terrestrial compartment and how much in the lake?

- Top-down approach:

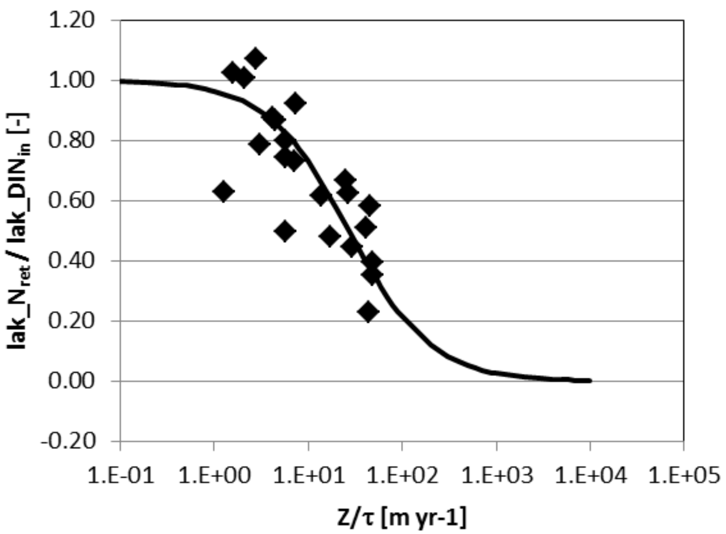
$terr\_N_{ret} = terr\_N_{i} + terr\_N_{u} + terr\_N_{de}$

(parameters according to Posch et al. 2007, Environmental studies no 0709, FOEN)

$lake\_N_{ret} = N_{dep} – terr\_N_{ret} - N_{out}$

- Bottom-up approach:

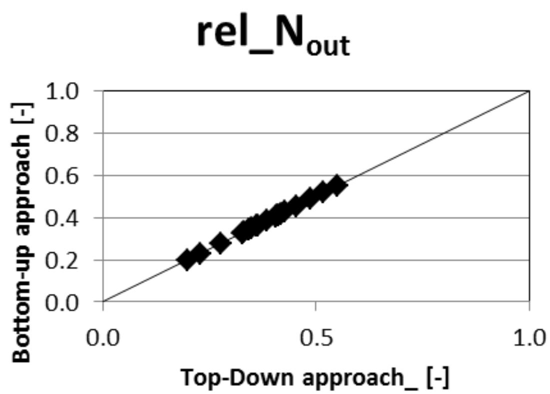
$lak\_N_{ret} = (rel\_lak\_N_{ret} * N_{out}) / (1- rel\_lak\_N_{ret}) -> lak\_N_{ret} / lak\_DIN_{in} = f(Z/T)$

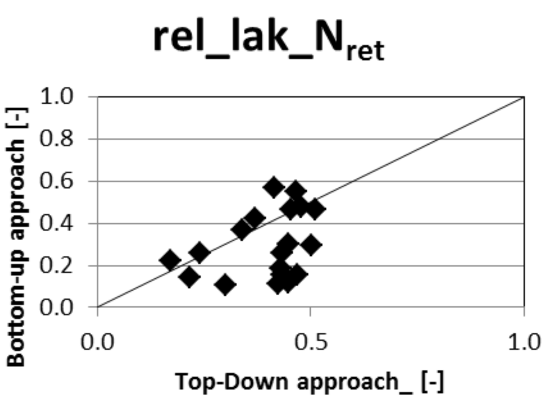


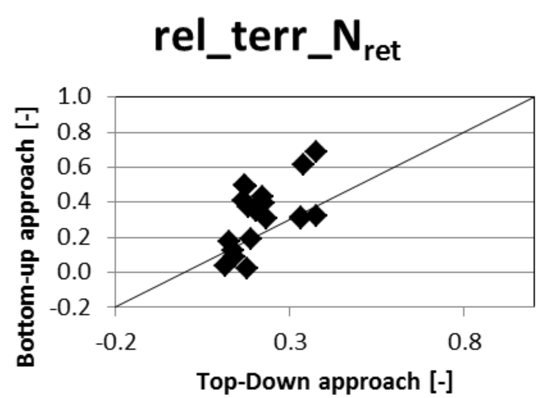
Data source:
Ahlgren et al. 1994, Ambio 23(6): 367-377
Andersen 1974, Arch. Hydrobiol. 74(4): 528-550
Gibson et al. 1992, Int. Revue ges. Hydrobiol. 77(a): 73-83
Hayward and Gibson 1993, Proc. R. Ir. Acad. 93B(1): 33-44
Institute for Ecosystem Study 2001-2009
Jensen et al. 1992, Int. Revue ges. Hydrobiol. 77(1): 29-42
Molot and Dillon 1993, Biogeochemistry 20: 195-212
Serruya 1975, Verh. Internat. Verein. Limnol. 19: 1357-1369
Steingruber 2001, Diss ETH Nr. 13939

$terr\_N_{ret} = N_{dep} – lak\_N_{ret} - N_{out}$

$rel\_terr\_N_{ret} + rel\_lak\_N_{ret} + rel\_N_{out} = 100\%$







Average values:

	$rel\_terr\_N_{ret}$	$rel\_lak\_N_{ret}$	rel_N_{out}
N_{ret} Top-down	22 ± 9%	40 ± 10%	38 ± 9%
N_{ret} Bottom-up	32 ± 18%	30 ± 16%	38 ± 9%

Assuming 20% more N output because of seasonality:

	$rel\_terr\_N_{ret}$	$rel\_lak\_N_{ret}$	rel_N_{out}
N_{ret} Top-down	22 ± 9%	32 ± 11%	46 ± 11%
N_{ret} Bottom-up	19 ± 22%	35 ± 19%	46 ± 11%

Conclusions

- Depositions of especially S but also N significantly decreased since 1980's
- In most lakes export of sulphate and nitrate from high altitude lakes decreased, sulphate mainly between 1980's-2000, nitrate after 2000
- Significant release of S and BC from high altitude lake catchments (mean altitude > 2400 m) due to increased melting of permafrost especially during the last 10-15 years, the release is increasing, S_{rel} more than BC_{rel}
- Concentration trends in high-altitude lakes in Southern Switzerland 2005-2015 :

	SO4	NO3	BC	Gran Alk	H
Significant decreasing trends	14	8	17	0	0
Significant increasing trends	2	0	1	0	1
No significant trends	4	12	2	20	19

- Relative retention of nitrogen in lake catchments between 40% and 87% and constant during the last 15 years and is mainly determined by the «velocity» water flows through the catchment.
- Although lake surfaces are small compared to the surfaces of the entire catchment (1-18%), their importance in retaining N is equal or even higher than that of the terrestrial compartment of the catchments -> high altitude lakes are important N buffers


Thanks for the attention!