Glacier compensation effect: Change of streamflow variability in Alpine catchments

UNI FREIBURG

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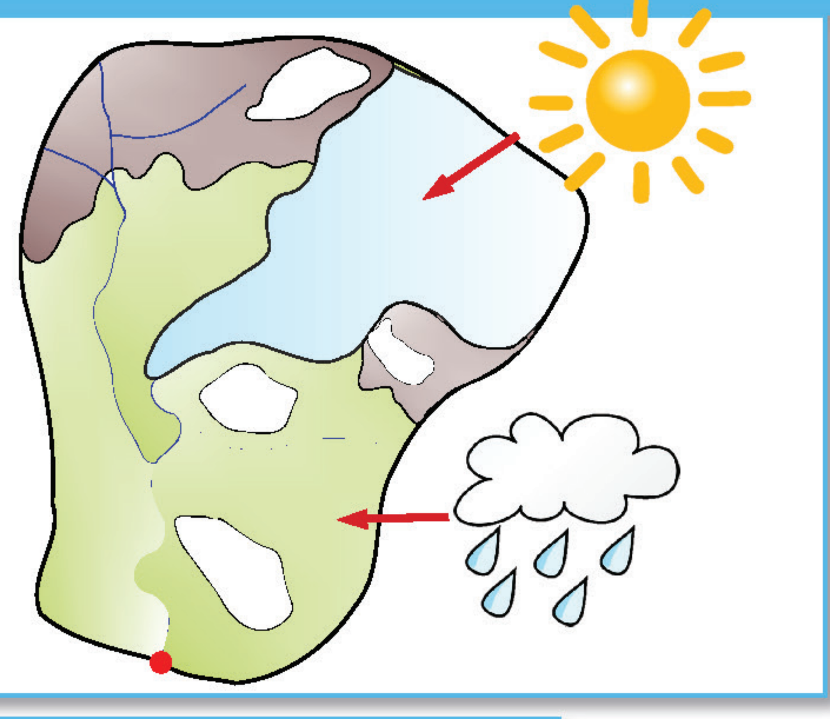
INTRODUCTION

THEORY

Glaciers are not only important water resources, contributing to streamflow by glacier melt, but also crucial moderators of streamflow. The moderating role of glaciers is described as the glacier compensation effect.

This effect is caused by an opposite response to precpicitation in the two parts of a glacierized catchment: the glacierized part and the non-glacierized part. The main controlling factor of melt is the surface energy balance, whereas precipitation is the main driver of runoff in the non-glacierized areas. During precipitation events, solar radiation is reduced, which has a negative effect on the runoff from the glacierized part of the catchment. Opposite, during warm and dry conditions, runoff from the glacierized part is favored.

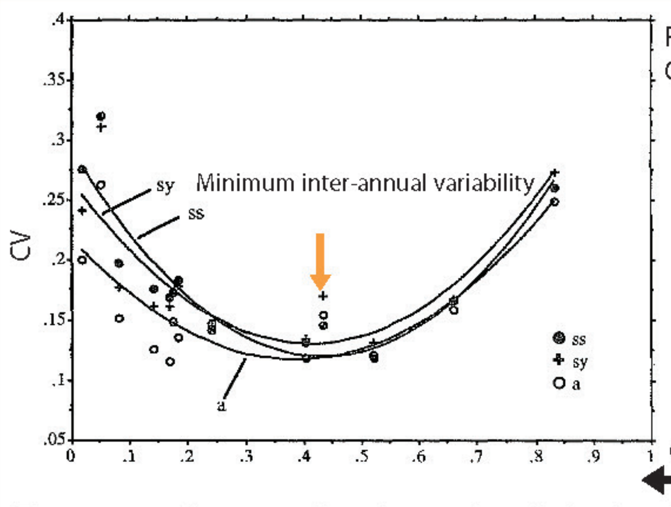
Thus, in cooler and wetter years (periods), runoff is arising from precipitation over the ice-free part of the catchment, offsetting the reduced glacier melt. In warm and dry summers (periods), enhanced glacier melt is compensating for the reduced precipitation, resulting in lower inter-annual streamflow variations for moderately glacierized catchments.



HYPOTHESES

- Spatial differences in variability and glacier cover are proxy for changes in variability over time (space-for-time substitution)
- Variability will increase/decrease depending on 'optimum glacier cover'
- 'Optimum glacier cover' depends on climate and catchment characteristics
- The compensation effect is more pronounced at longer time scales (day to year & daily to annual streamflow)

LITERATURE REVIEW

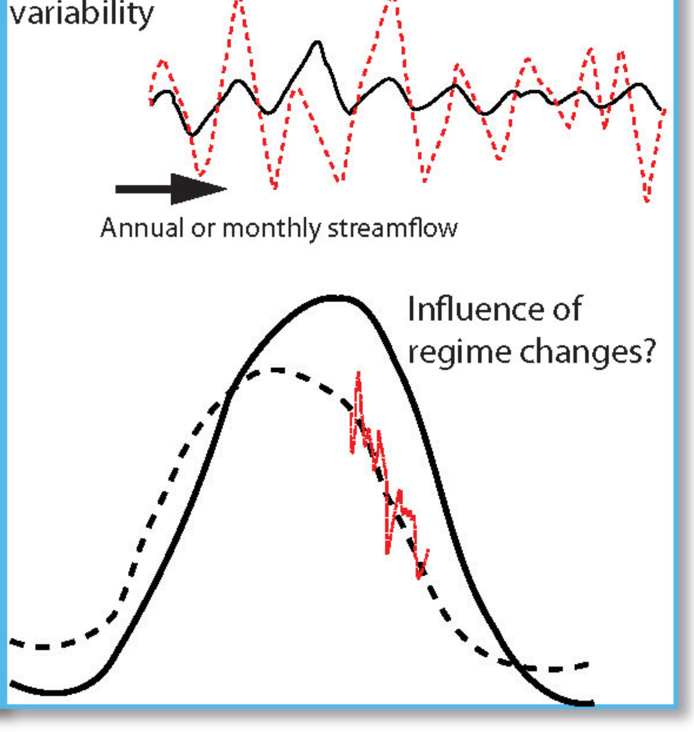


From Chen & Ohmura (1990)

The coefficient of variation (CV) is determined for annual and seasonal streamflow and plotted against fraction glacier cover

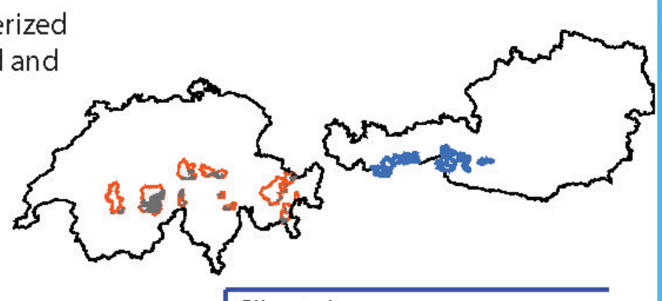
The streamflow moderating role of glaciers has been analysed in a few studies (e.g. Fountain & Tangborn, 1985; Chen & Ohmura, 1990). They found that the 'optimum glacier cover' (=lowest inter-annual variability) is around 40%, but it can vary for different regions. At both ends of the curve, either precipitation or radiation is dominating the variability.

CHANGE



DATA

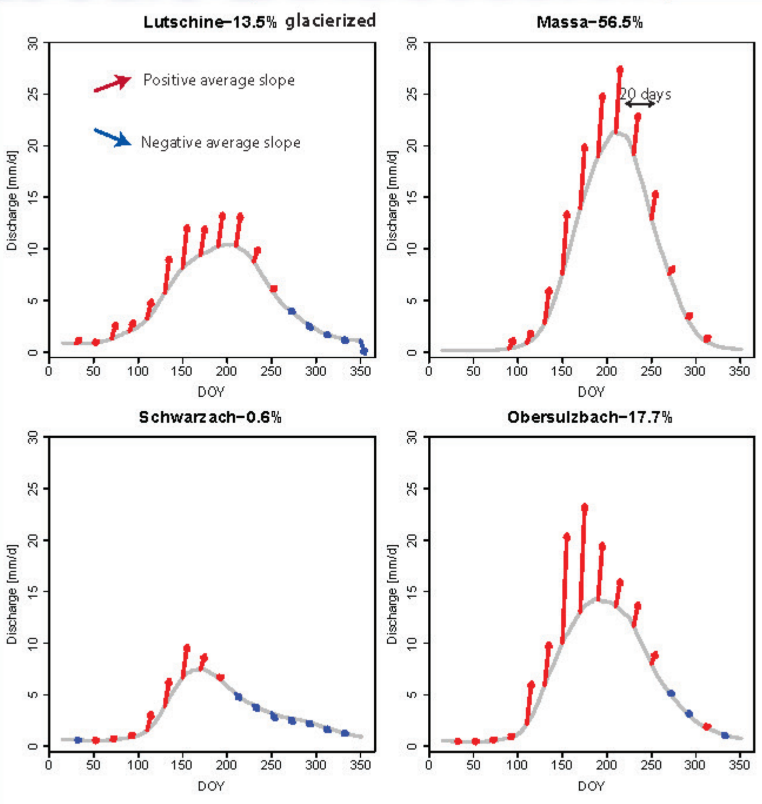
- Streamflow data of glacierized catchments in Switzerland and Austria
- Glacier cover range: 0.0% - 56.5% (2010)
- Catchment size: 14 - 530 km^2, elevation ranges: 1470 - 3560 m
- Main period of analysis: 1975-2014 (15 catchments in both Switzerland and Austria)
- Gridded precipitation (P) and temperature (T) data (1x1 km)



Climatology
- Annual precipitation Switzerland: 1000 - 2500 mm Austria: 1000 - 1600 mm
- Annual maximum precipitation June, July and August
- Mean monthly temperatures > 0° C May - October

RESULTS & DISCUSSION

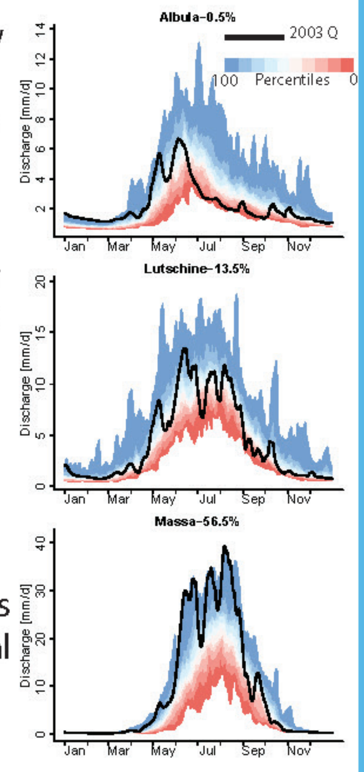
COMPENSATION EFFECT



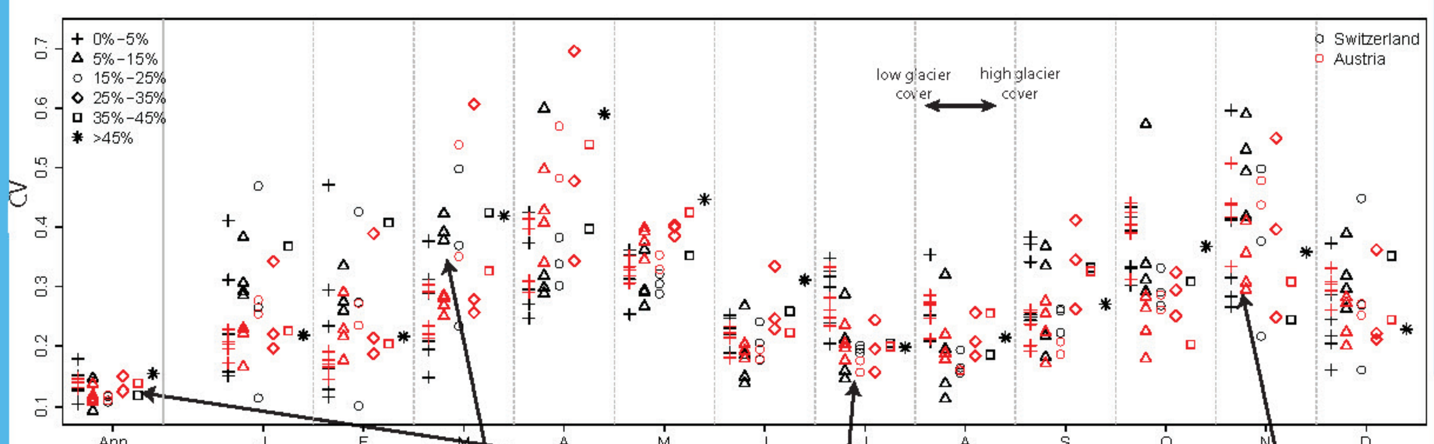
Slope of streamflow 'recession curves' during period of no P > 3 d & T > 0.5 °C

Catchments with higher glacier cover can buffer P deficits more

Also during 'extreme years', e.g. 2003, Q shows an opposite signal for low and high glacier covers



VARIABIIITY - GLACIER %



lowest CV

differences between Austria and Switzerland

'curve effect' variability is decreasing with increasing glacier cover

large differences within glacier cover classes

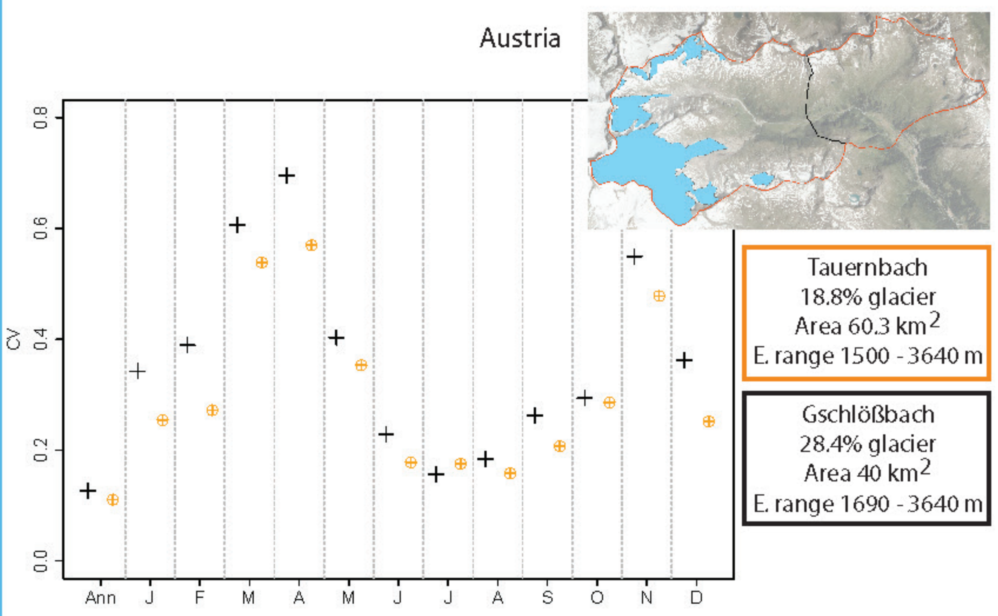
Coefficient of Variation (CV)

$$CV = \frac{\text{St. deviation}}{\text{Mean}}$$

measure for inter-annual variability

monthly CV lowest

NESTED CATCHMENTS



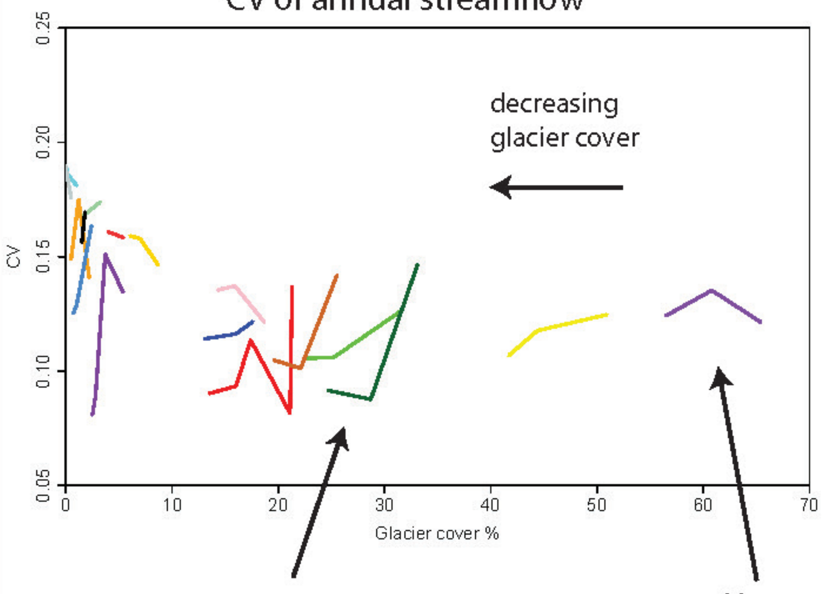
Tauernbach
18.8% glacier
Area 60.3 km^2
E. range 1500 - 3640 m

Gschlößbach
28.4% glacier
Area 40 km^2
E. range 1690 - 3640 m

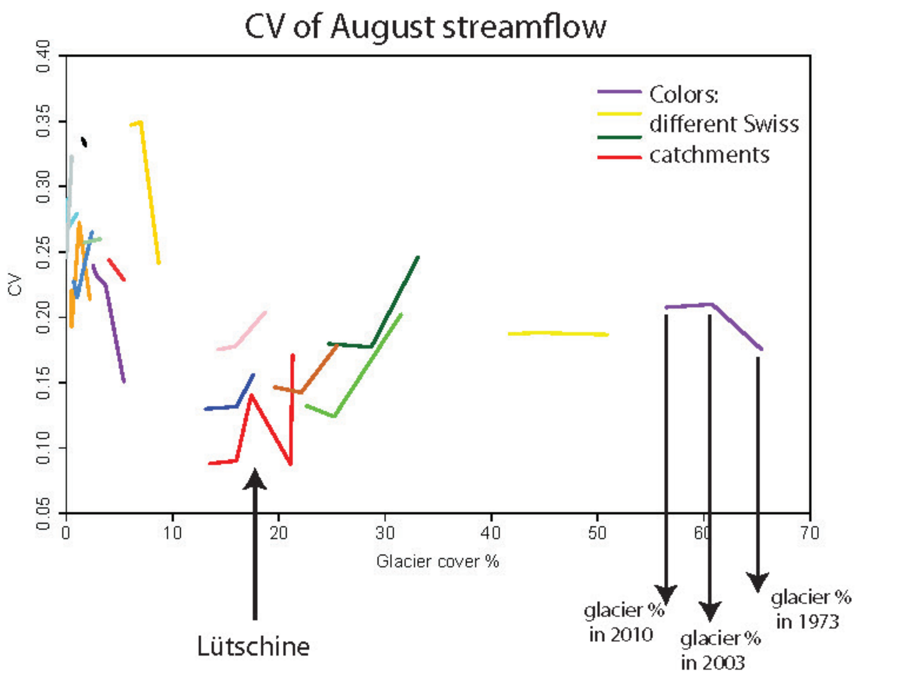
In these catchments 'only' glacier % differs. Variability is, for both annual and monthly streamflow, higher for the higher relative glacier cover. This would suggest that the 'optimum glacier cover' is smaller than 28%, which is not expected from the 'optimum curve' presented in the literature.

CHANGE IN VARIABILITY

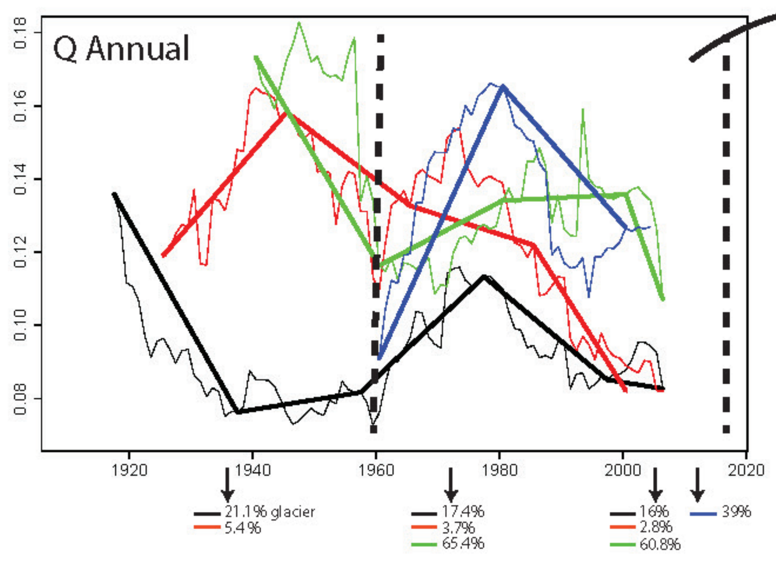
CV of annual streamflow

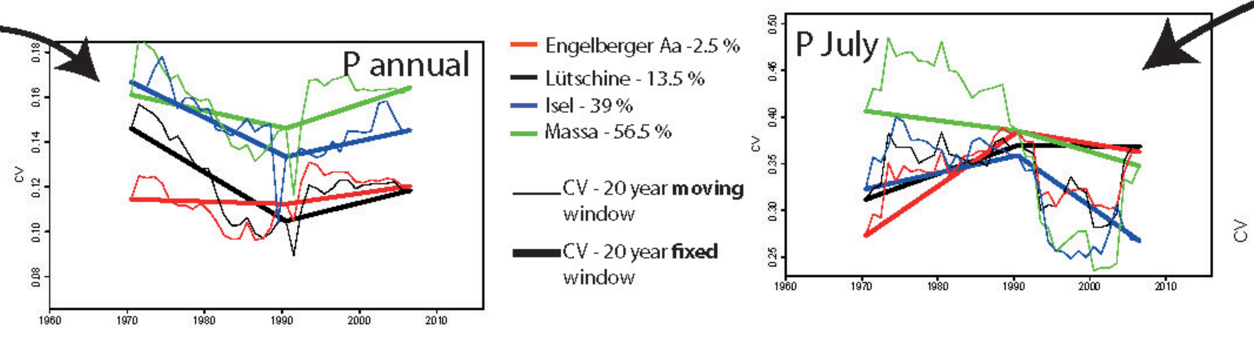


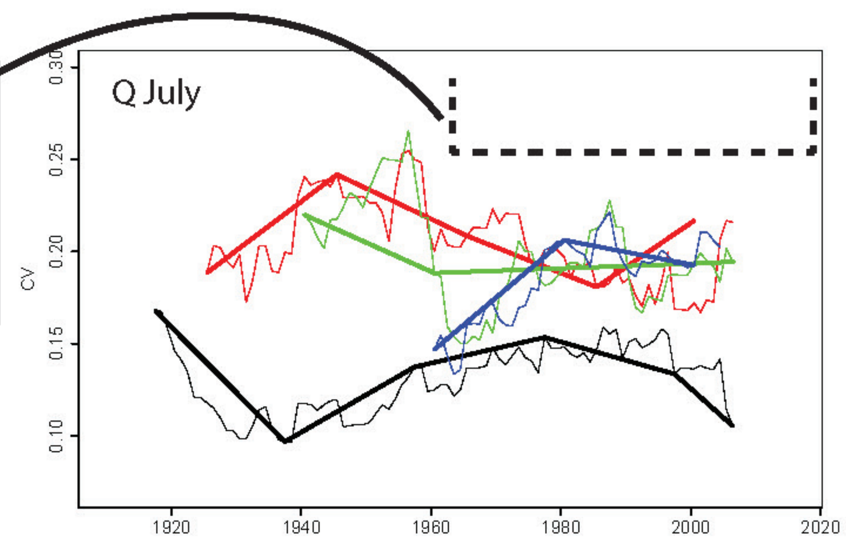
CV of August streamflow



Spatial and temporal comparison of changes in CV with glacier cover. Glacier covers where derived for 1900, 1935, 1973, 2003 and 2010. If streamflow data was available, CV was calculated around these glacier cover dates: 1908-1928, 1925-1945, 1963-1983, 1993-2013 and1996-2016. Variability is high for low glacier covers (< 5%). For most catchments, the CV decreases over time, although for some the CV increases.

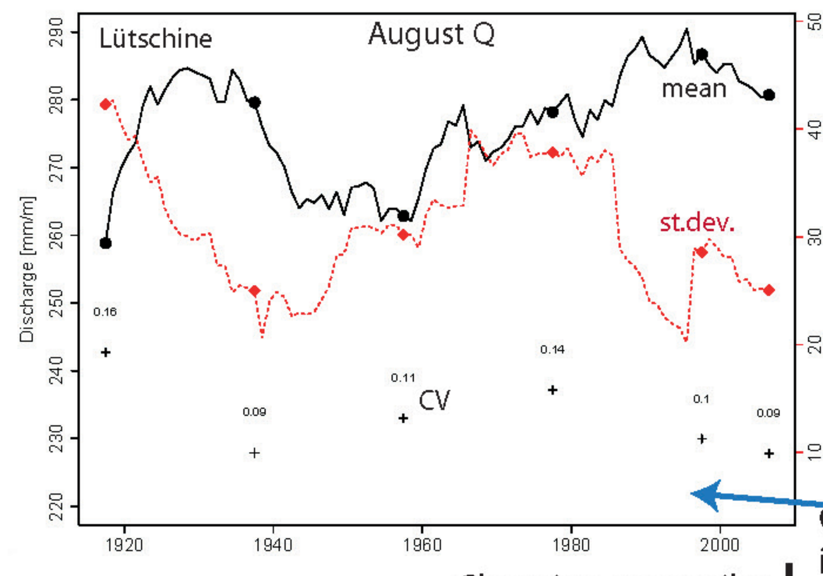






Patterns of changing CV look in general similar for annual and July streamflow. Inter-annual variability is higher for the low and high glacier covers. Lütschine is the only catchment where annual Q CV is lower than annual P CV. For July, Q variability is lower than P variability. Patterns of changing CV in time are difficult to compare between catchments and with changes in P variability.

CHANGING MEAN & PERCENTILES

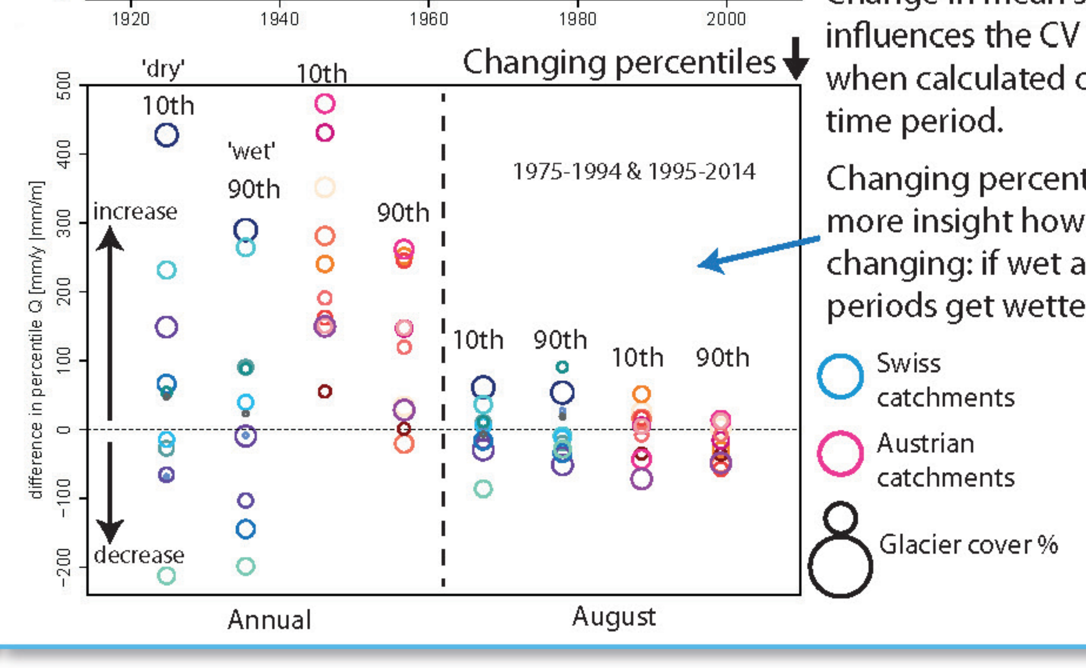


Change of mean, standard deviation and CV over time

Besides changes in variability, other hydrological changes occur in glacierized catchments as well, possibly affecting variability.

Change in mean streamflow influences the CV and st. dev. when calculated over a long time period.

Changing percentiles



Changing percentiles can give more insight how variability is changing: if wet and dry periods get wetter or drier.

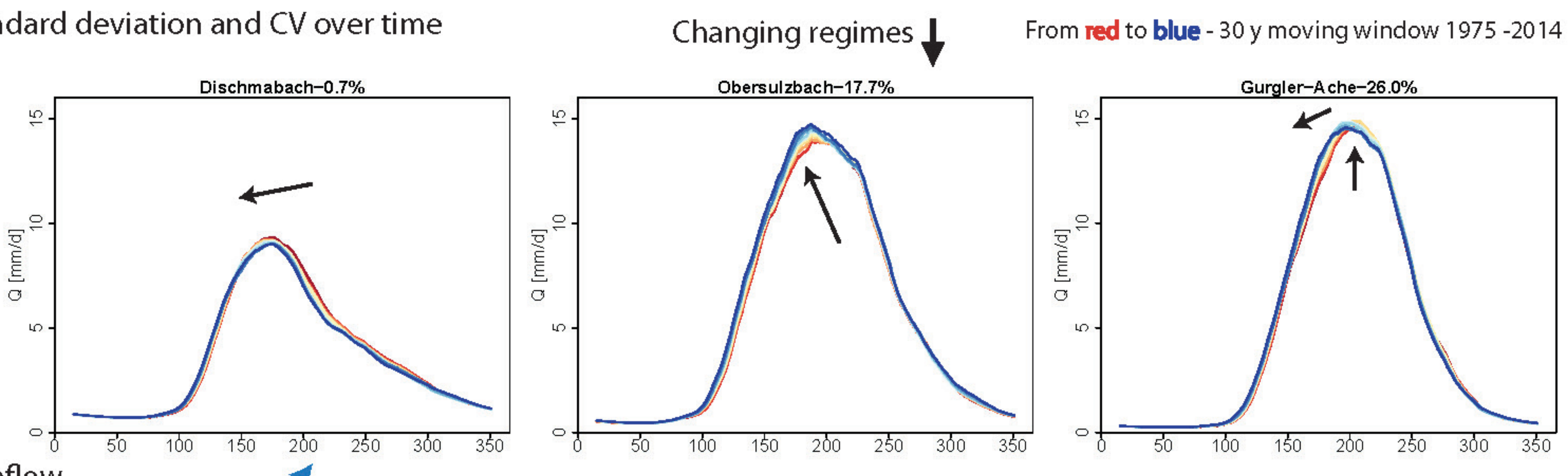
Swiss catchments

Austrian catchments

Glacier cover %

Changing regimes

From red to blue - 30 y moving window 1975 -2014



Shifts in the regimes change the mean streamflow and it can also affect inter-annual variability in months surrounding the main melt season.

OUTLOOK

- Time scales of variability: inter-annaul variability on higher temporal resolution -- within-year variability
- Include elevation, snow cover and (more detailed) climatology data (warm & dry summers?) in analysis
- Meaning of change in CV (virtual time series) -- is CV good measure?
- Modelling experiment with changing glacier cover
  > Calibration?

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Data: BAFU switzerland, Meteoschweiz, ZAMG

References:
- Chen, J., & Ohmura, A. (1990). On the influence of Alpine glaciers on runoff. IAHS Publ, 193, 117-125.
- Fountain, A. G., & Tangborn, W. V. (1985). The effect of glaciers on streamflow variations. WRR, 21(4), 579-586.