Hydrological response to warm and dry extremes in glacierized catchments: when and how are glaciers compensating?

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Hello, I am Marit van Tiel, a PhD student at Uni Freiburg, and would like to tell you about my work on streamflow variability in glacierized catchments

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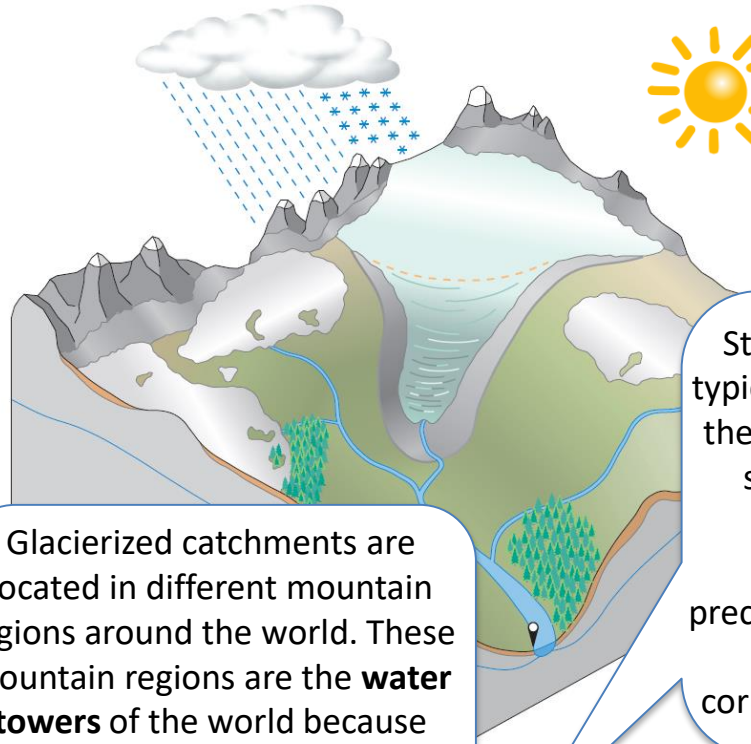
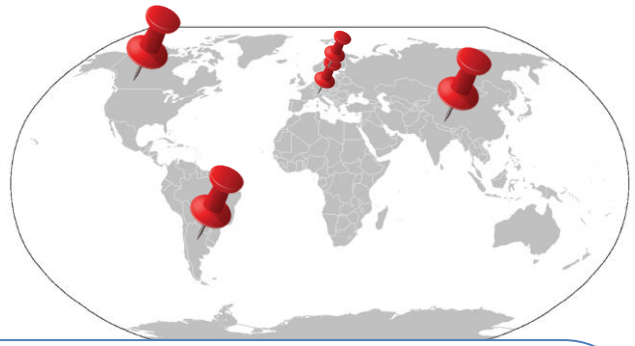
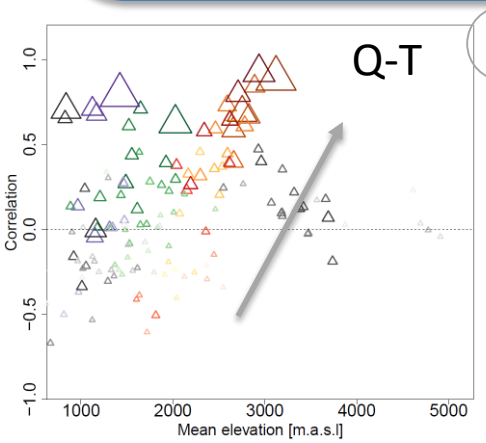
Glacierized catchments and their streamflow





Glacierized catchments are located in different mountain regions around the world. These mountain regions are the **water towers** of the world because they supply water (melt) to downstream areas

Streamflow from glacierized catchments show a typical **seasonal hydrological regime (1)**. The higher the relative glacier cover fraction, the stronger the seasonality. This general pattern is similar for catchments around the world, but there are differences, for example due to different precipitation regimes and catchment characteristics. Streamflow of highly glacierized catchments correlate strongly with **temperature variations (2)**.



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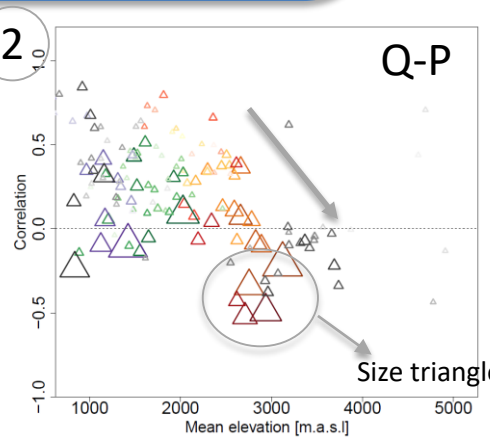
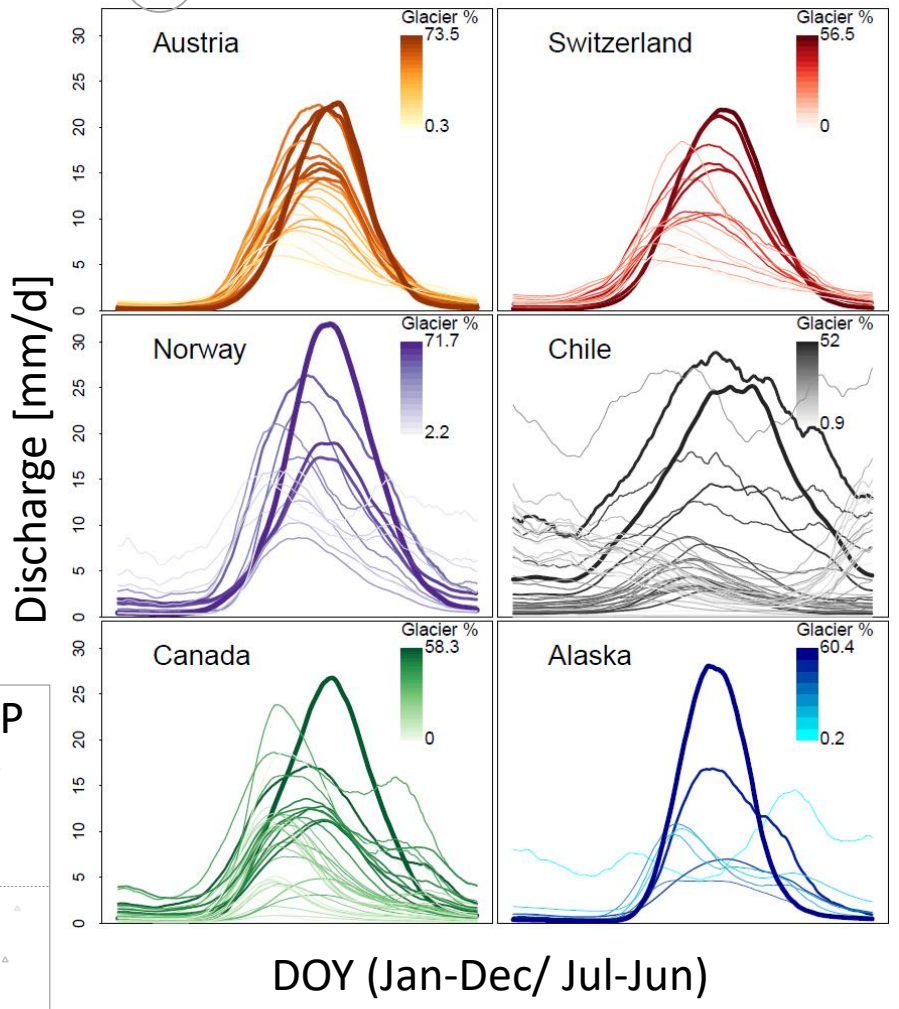


Hydrological regime

Measured streamflow data from many catchments around the world

1

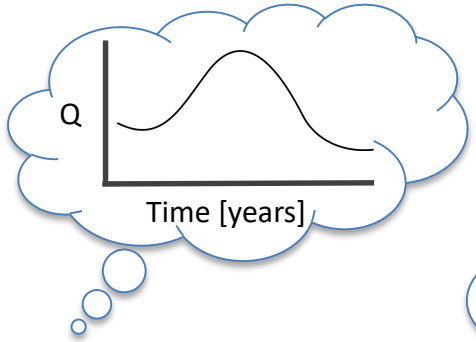


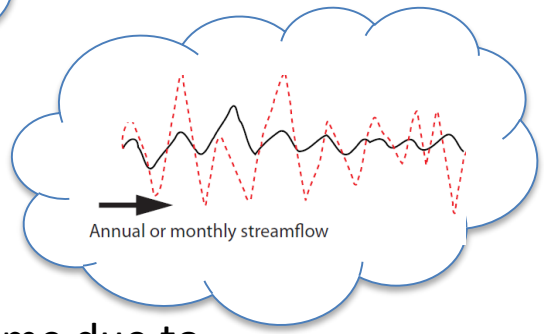
Size triangles indicate glacier cover fraction

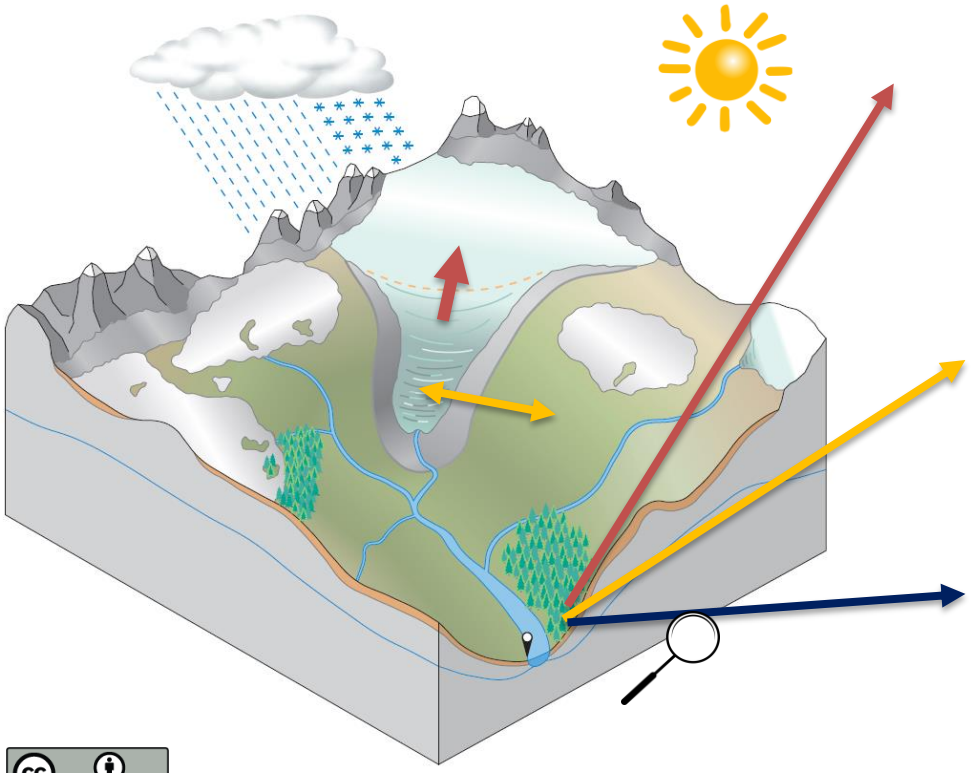
van Tiel et al., EGU 2018

Hydrological response to warm climate and warm and dry weather

Glaciers can compensate for a lack of rainfall-runoff in warm and dry climate and weather, because glacier runoff is driven by temperature rather than precpitation. Compared to snow, the glacier storage is not related to winter precipitation (on shorter timescales). **The question is what effect this compensation effect has on streamflow at different timescales and in different catchments.**





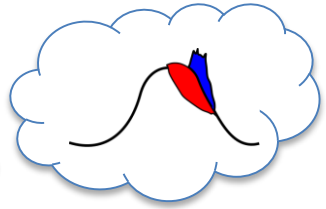


1. Long-term variability

When glaciers compensate is changing over time due to climate change and glacier retreat
Where glaciers retreat, streamflow initially increases

2. Interannual variability

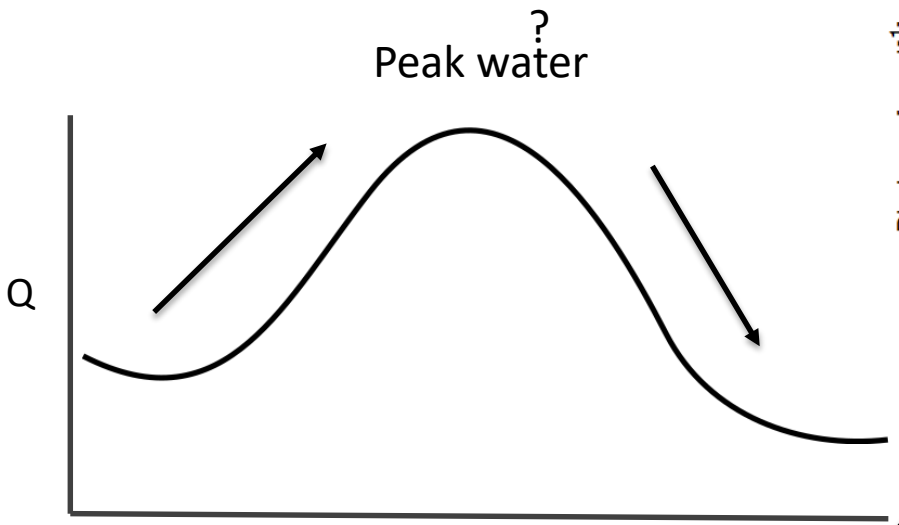
When glaciers compensate the interannual streamflow variability is reduced
Where variability is lowest depends on glacier cover fraction and other characteristics

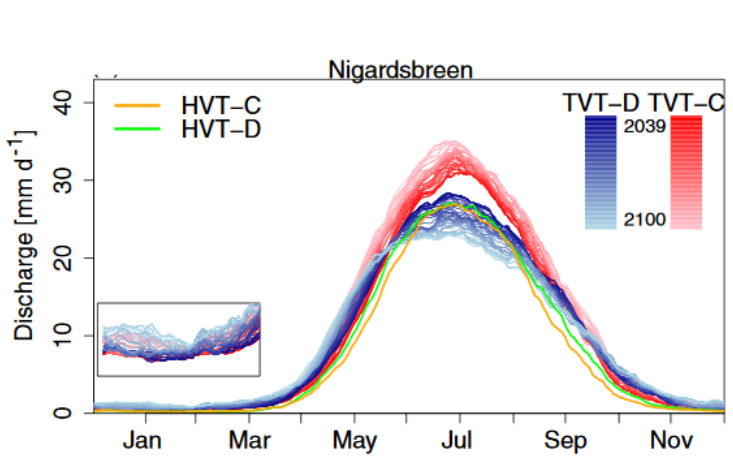


3. Glacier melt buffer to warm & dry events

When glaciers compensate they do that especially during warm and dry extremes
Where glaciers buffer there is a certain resilience to drought conditions

Long term changes of streamflow





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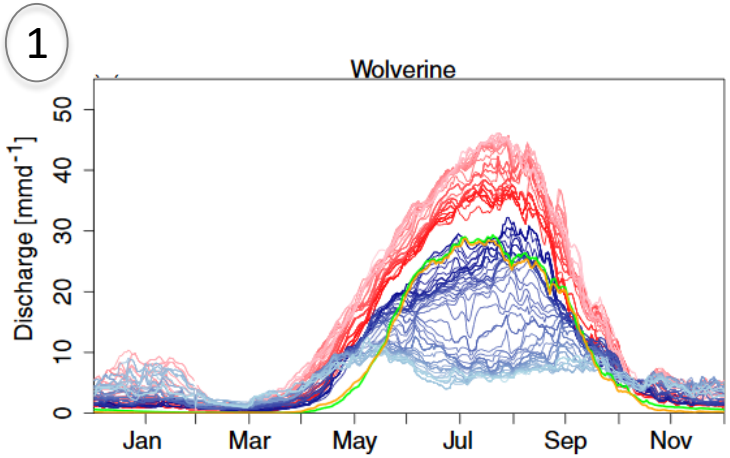
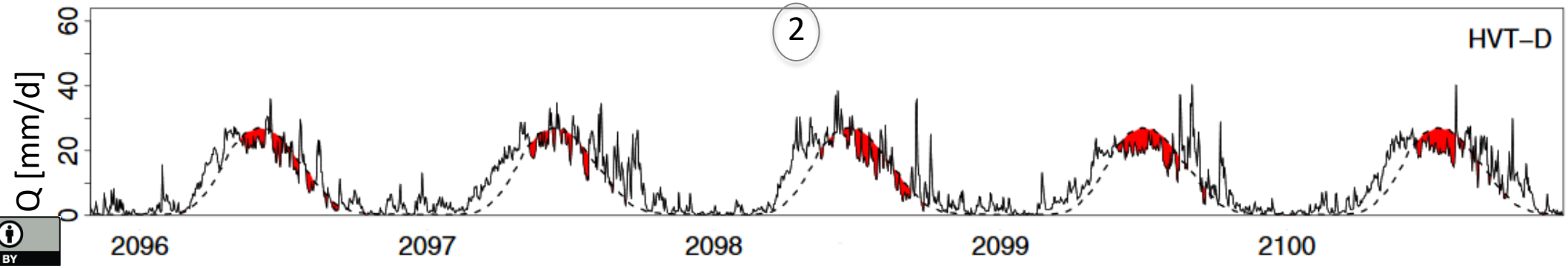


van Tiel et al., 2018

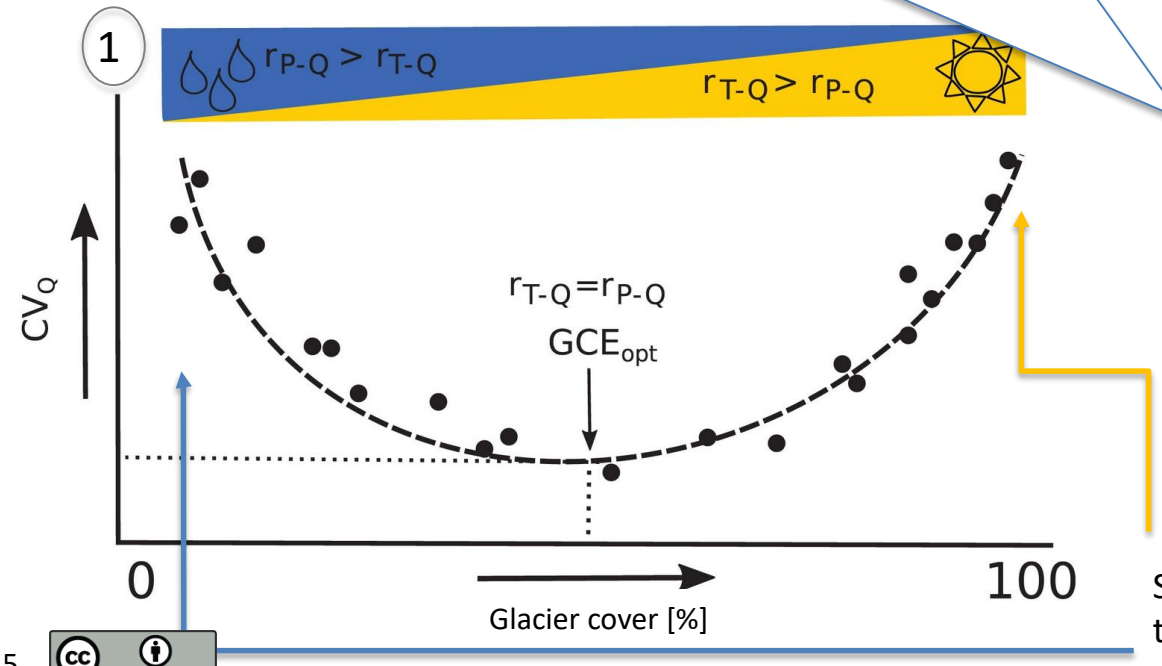
Due to climate warming, glaciers are retreating, which affects the downstream water supply. In a warming climate, glaciers will initally melt more, but the glacier volume will decrease, eventually leading to less glacier melt contribution. The change point can be in the past or in the future and the timing is different for catchments and regions. In the future, when glaciers have retreated significantly, regimes will change (1, showing a changing streamflow drought threshold), and there will be a lack of water in late summer compared to today's conditions (2).



Interannual streamflow variability

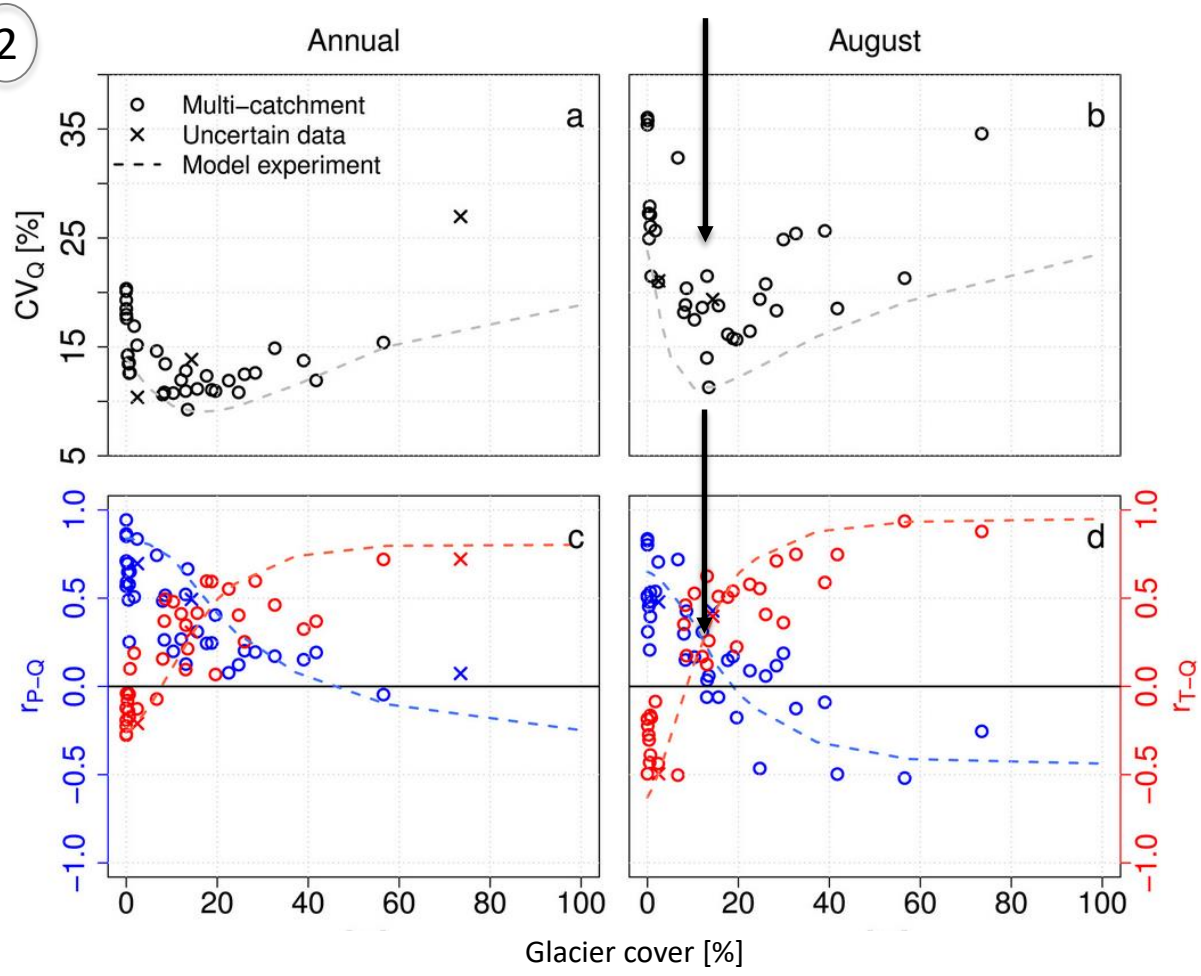
The **glacierized part** and **non-glacierized** part of a catchment together control the streamflow signal. The runoff from these two parts are **negatively correlated**. Runoff is high during **warm and dry** conditions in the glacierized part, and high during **cold and wet** periods in the non-glacierized part. If these two parts can counterbalance each other, interannual streamflow **variability is reduced** (1). Our study showed that this effect can be **modelled** and that an optimum glacier cover, where variability is lowest, is between 10-15%. **Gauged catchments** in the **Alps** show a similar pattern but with more scatter and less clear relationship between streamflow variability and glacier cover fraction (2)

1



2

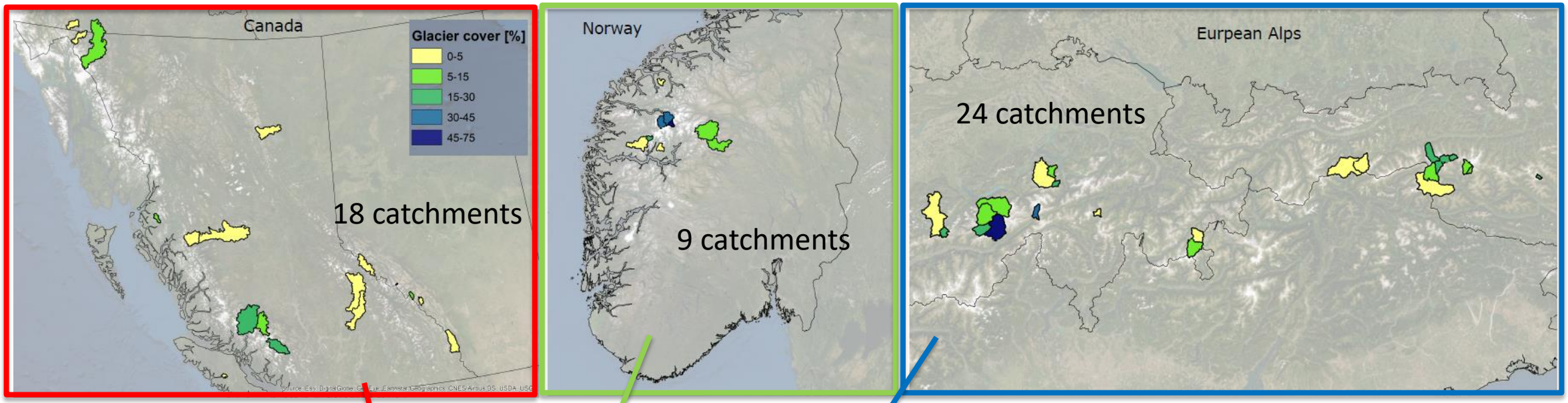
At the optimum, the correlations of T-Q and P-Q switch dominance

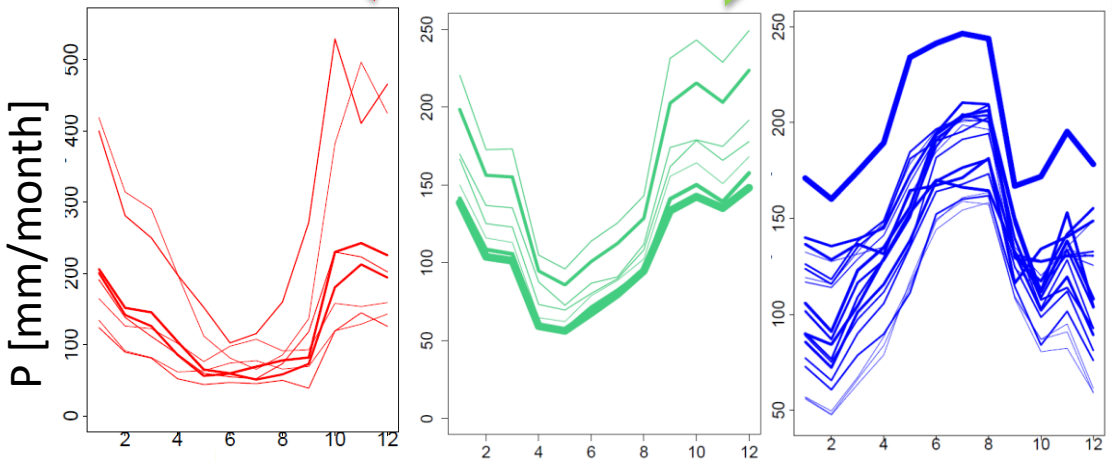


van Tiel et al., 2020

Streamflow variability high for low and high glacier covers: precipitation or temperature variability dominate streamflow

Buffer to warm & dry events – different regions



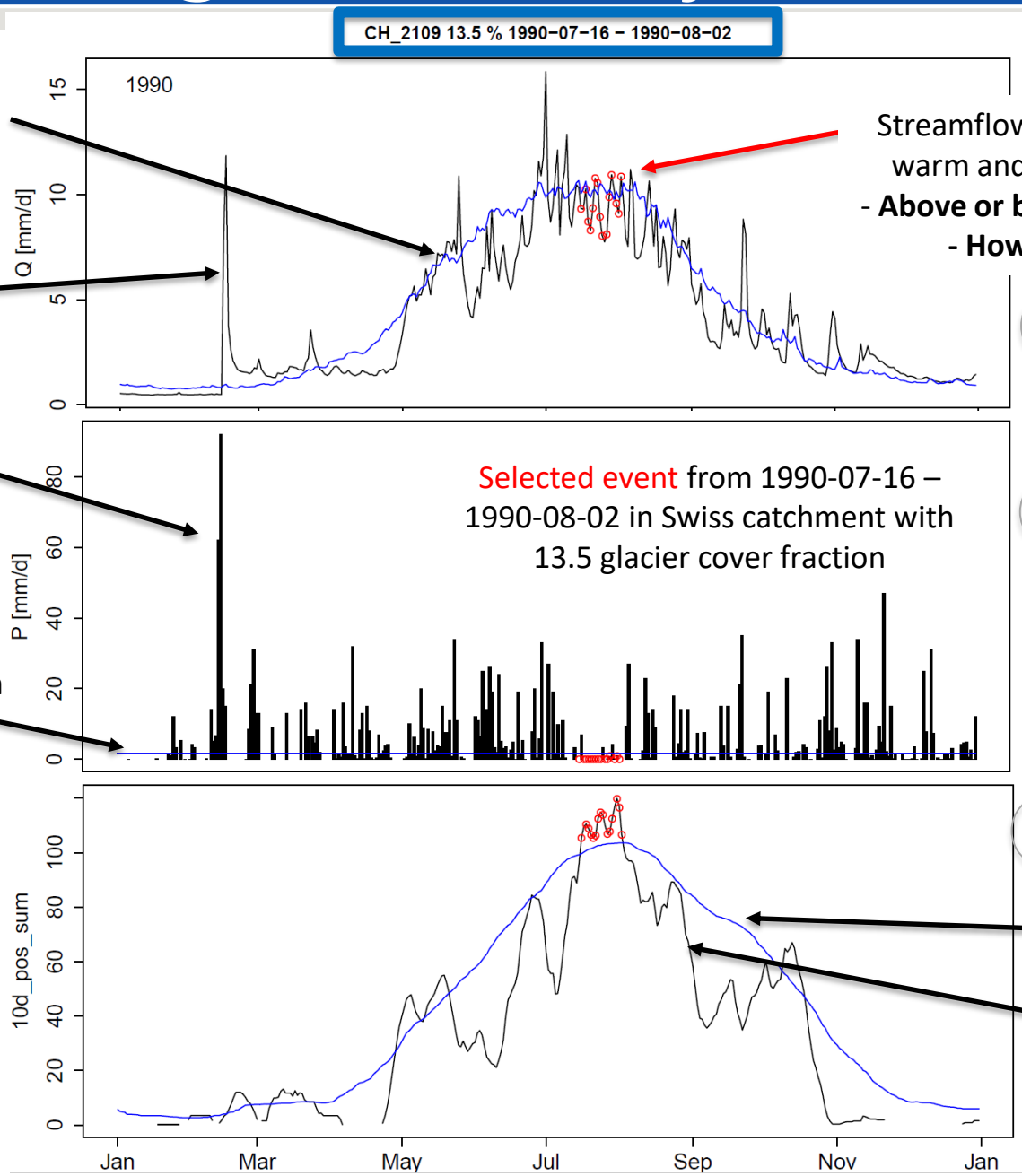


Different precipitation regimes

- Within regions
- Across regions
- Summer wet/ summer dry

Now, I am analyzing the hydrological response to warm and dry events in catchments with long streamflow records in Canada, Norway and the Alps. The catchments vary in size, elevation, glacier cover fraction and also climatic regime.

Selecting warm & dry events



Streamflow regime

Daily streamflow

Daily precipitation

Precipitation threshold 1.5 mm

Streamflow response to warm and dry events:
- **Above or below regime?**
- **How much?**

3

Selected event from 1990-07-16 – 1990-08-02 in Swiss catchment with 13.5 glacier cover fraction

1

2

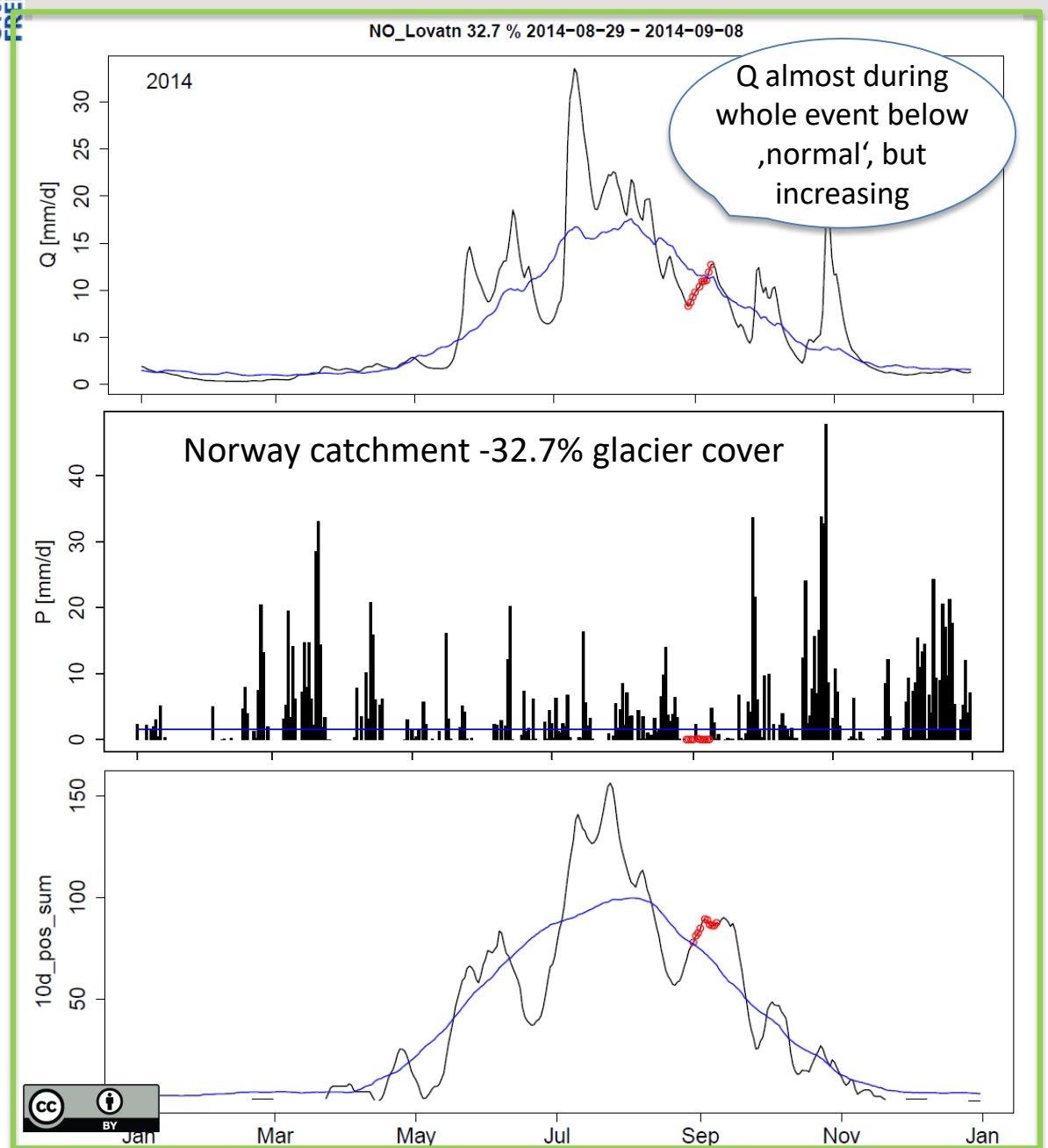
Temperature threshold

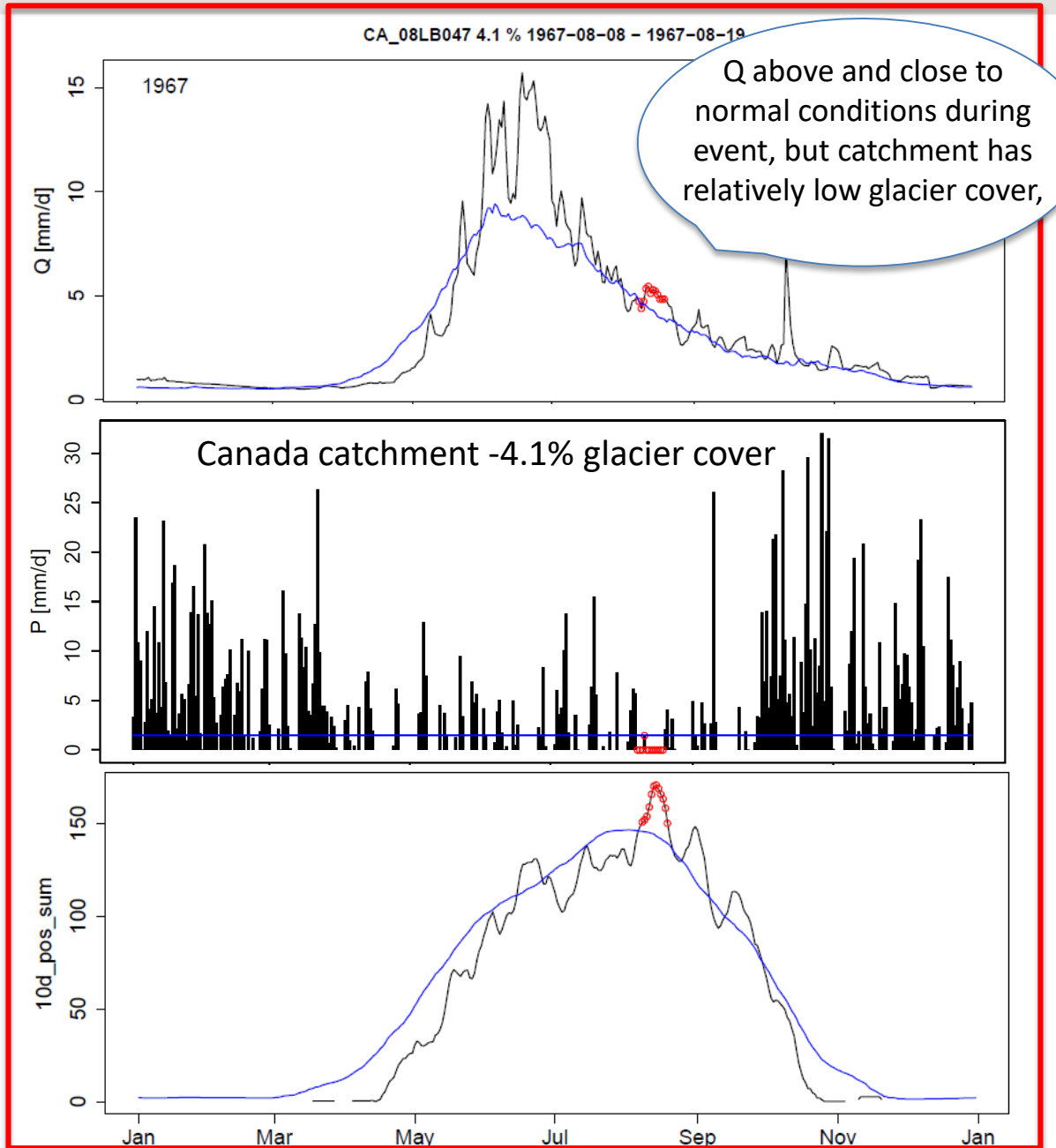
Temperature 10 days positive sum

I selected warm and dry events based on several criteria:

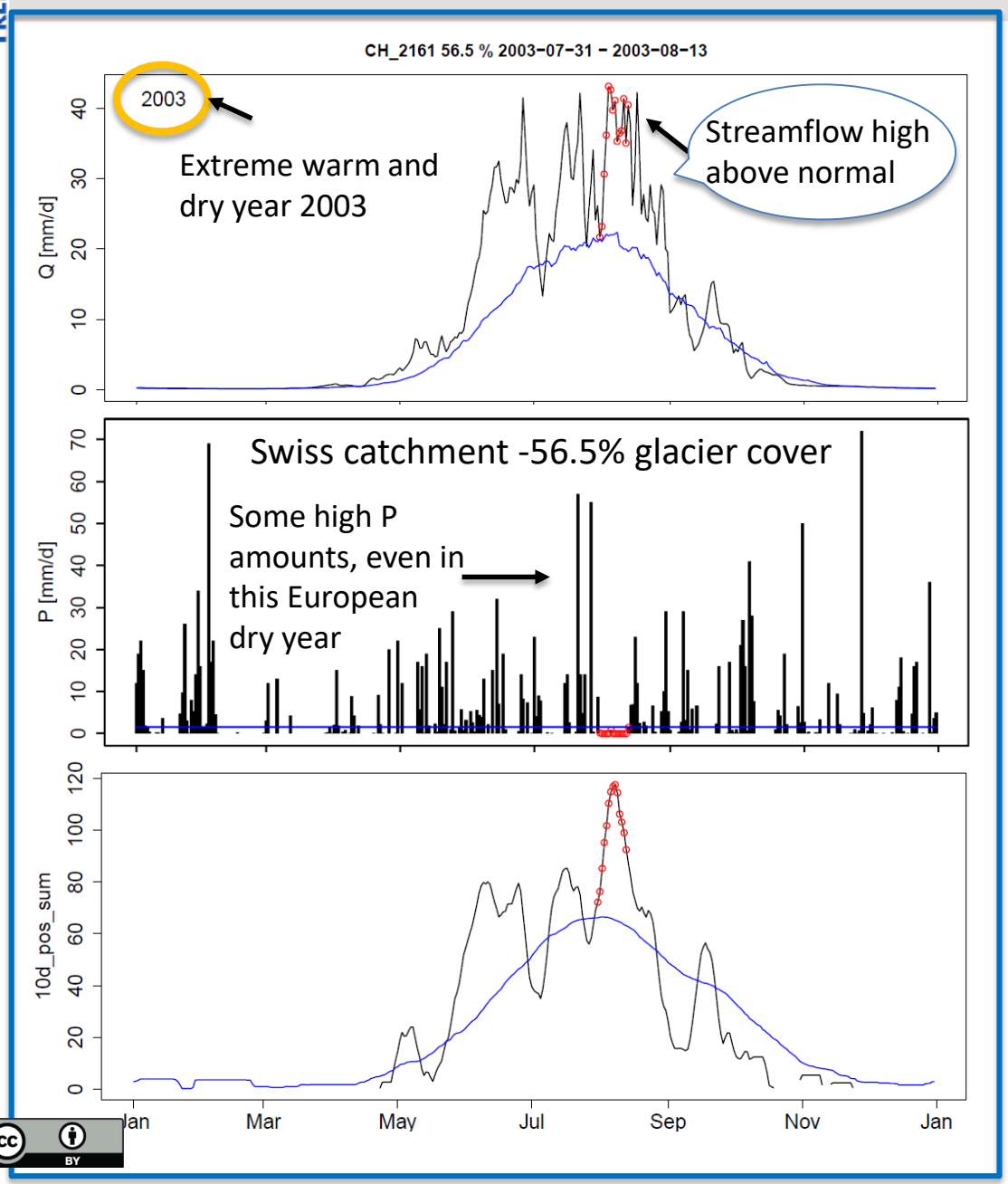
- precipitation should be below 1.5 mm
- the 10 day positive degree day sum should be above the threshold which is based on the 80th percentile (only 20% of the events in a certain period are warmer)
- The event should last at least 10 days
- If the event is interrupted by 1-2 days, the days before and after the interruption are taken together as one event

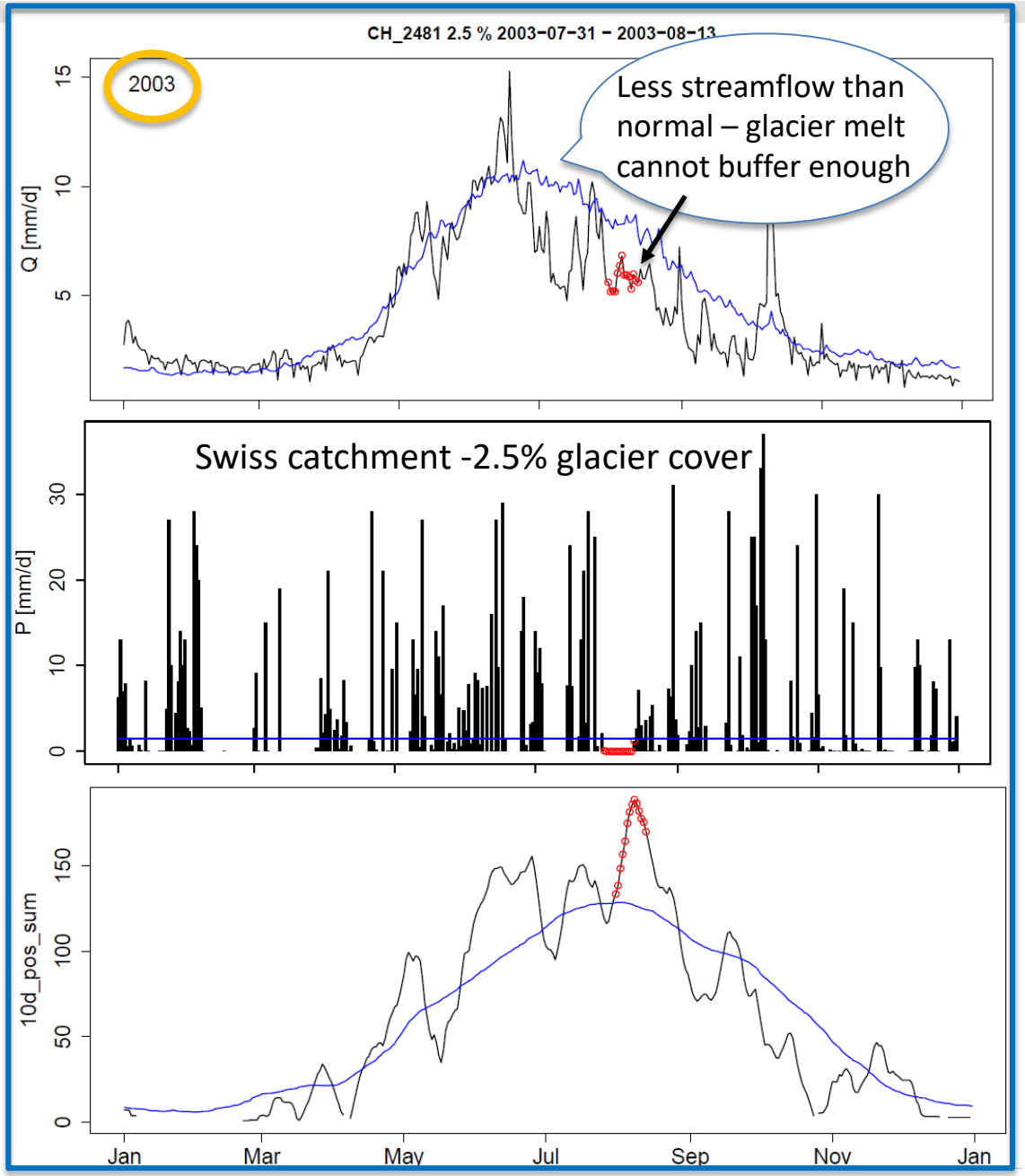
W&D events in all shapes and sizes



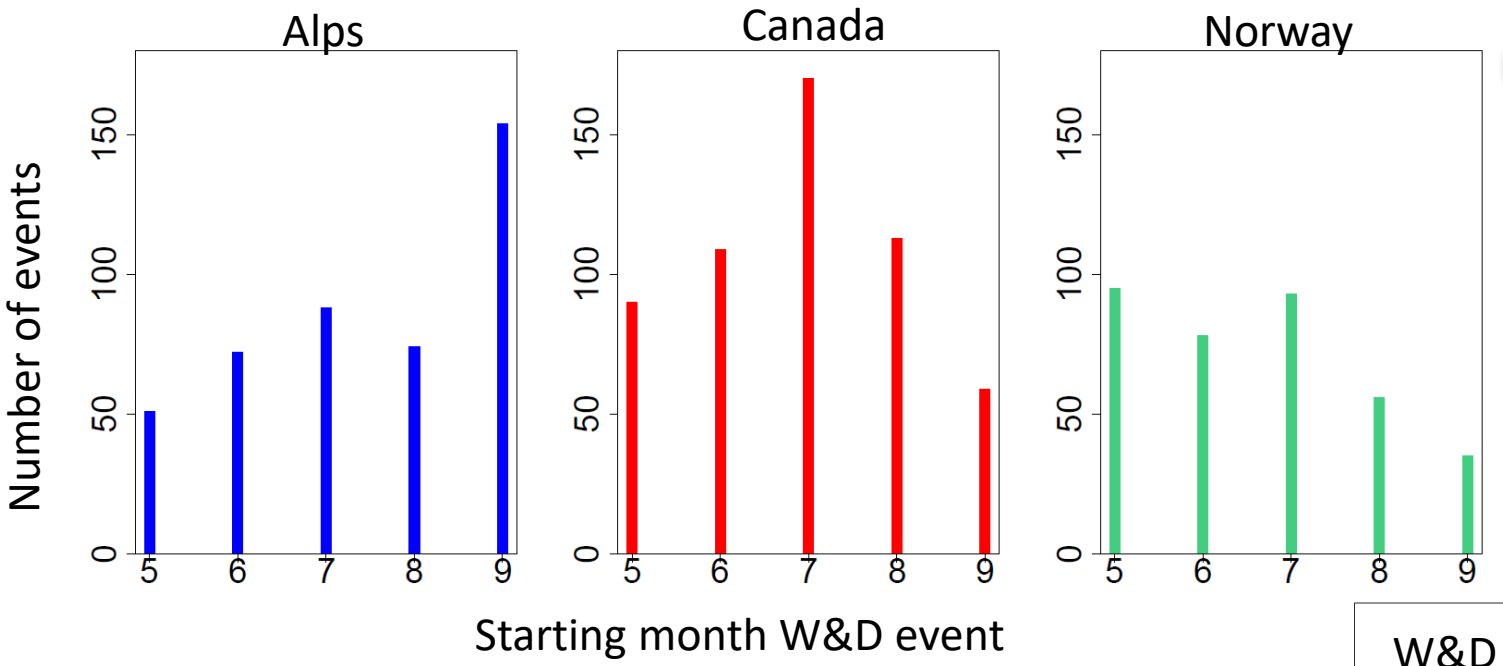


W&D events in all shapes and sizes





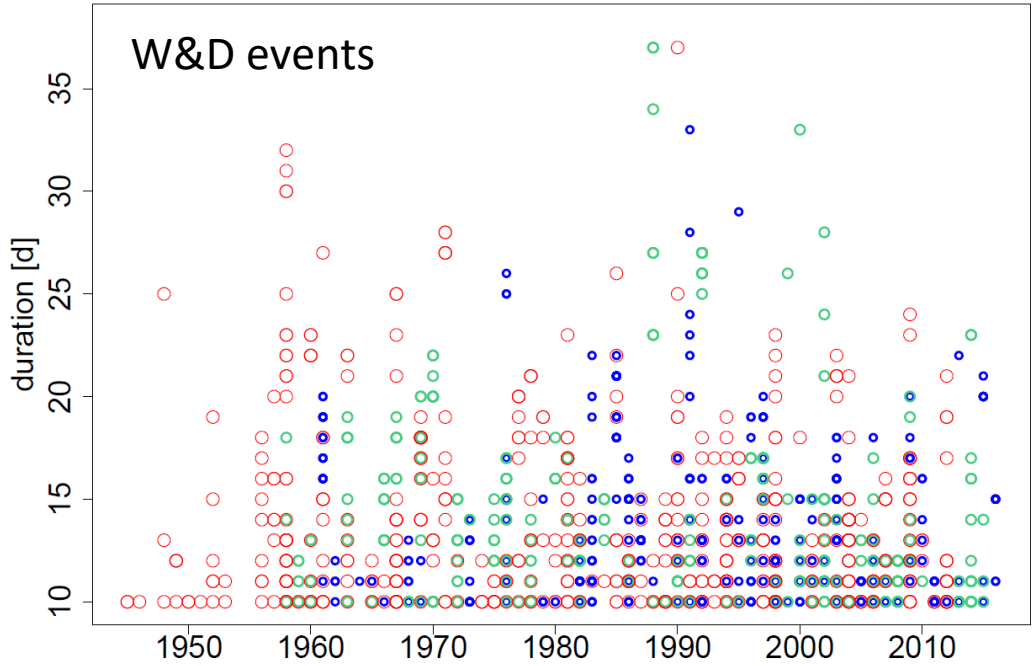
When do warm & dry events occur?



1

Number of events varies between the regions, partly because different number of catchments within each region and partly because of differences in climate

2

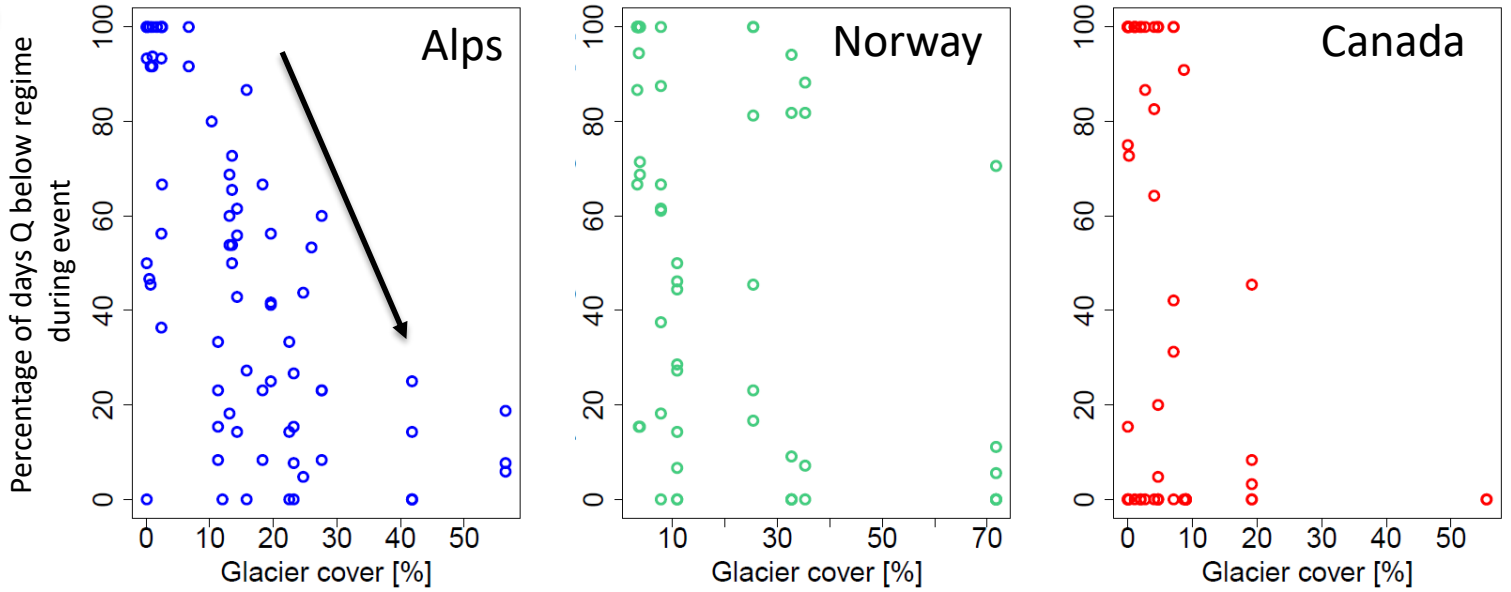


Most events start in September in the European Alps and during July in Norway and Canada (when precipitation shows a dip (slide 6). The events are distributed over the analysis period and the duration varies from 10 to more than 35 days

Streamflow response to warm & dry events in August

1

The higher the glacier cover fraction, the less days streamflow is below the normal regime during the event and the more streamflow is generated that is above the regime. Pattern is most clear for the Alps. Norway and Canada seem to have the switching point of negative to positive streamflow surplus at lower glacier cover fractions.



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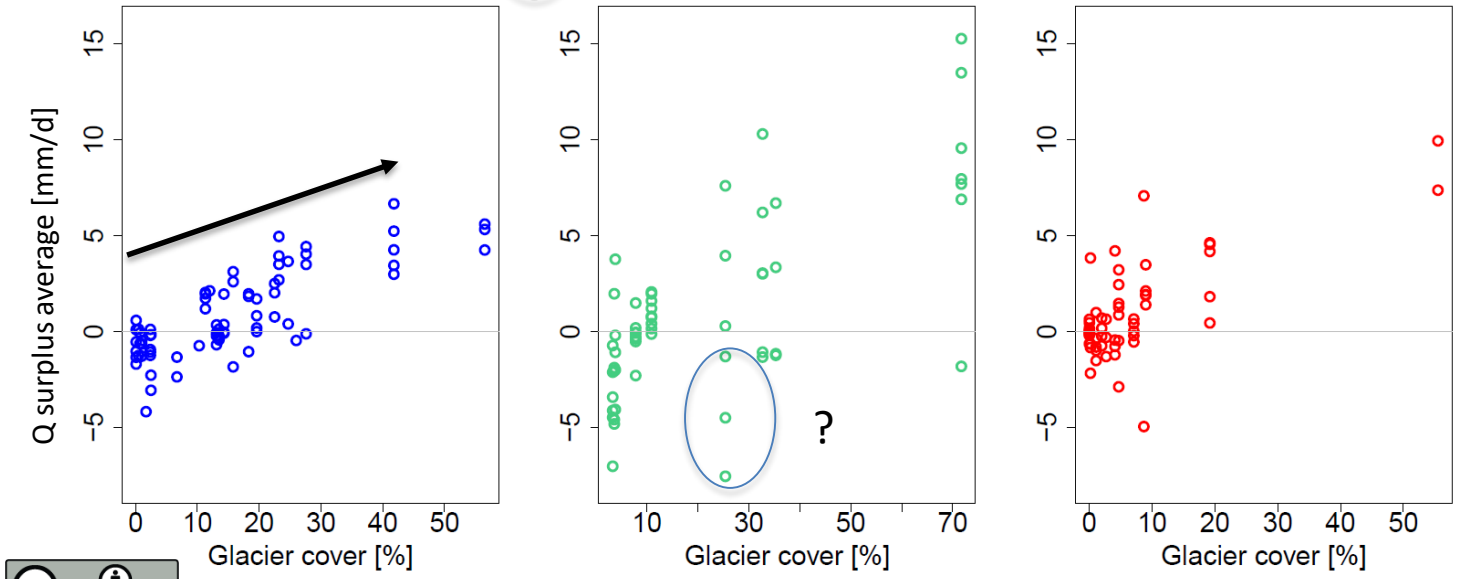

Glaciers can compensate during warm and dry weather

When - during most of the events if glacier cover is high enough (>10-15%), more detailed analyses needed for individual catchments and events

Where glacier cover fractions are high and possibly where summer rain is low

- Van Tiel, M., Teuling, A. J., Wanders, N., Vis, M. J. P., Stahl, K., and Van Loon, A. F. (2018) The role of glacier changes and threshold definition in the characterisation of future streamflow droughts in glacierised catchments, Hydrol. Earth Syst. Sci., 22, 463–485, https://doi.org/10.5194/hess-22-463-2018
- Van Tiel, M., Kohn, I., Van Loon, A. F., & Stahl, K. (2020). The compensating effect of glaciers: Characterizing the relation between interannual streamflow variability and glacier cover. *Hydrological Processes*, 34 (3), 553-568, https://doi.org/10.1002/hyp.13603
- Van Tiel, M., Van Loon, A. F., & Stahl, K. (2018). Variability in glacier hydrographs around the world. In *EGU General Assembly Conference Abstracts* (Vol. 20, p. 9663).

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