Rethinking the hydrological response in cryosphere-dominated catchments: from a snow focus to a subsurface-connected perspective

B. Schaefli[1], N. Ceperley[1], X. Fan[1,2]

1: Institute of Geography & OCCR, Univeristy of Bern,
2: now at: EPFL, Switzerland

UNIVERSITÄT BERN
OESCHGER CENTRE CLIMATE CHANGE RESEARCH

1) Context

- Streamflow during snowmelt season is controlled by evolving surface–subsurface interactions
- Input patterns from snowmelt <> rainfall
- Many snow-hydro modelling focuses on snow processes

Role of dynamic stream network
Role of groundwater feedback?

2) Precip-streamflow models have systematic difficulties

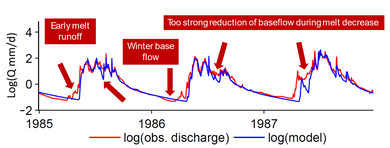

Fig. 1: Simulated and observed discharge Q of the Dischma river (CH) in log-scale (Spatially-explicit model with stream network convolution, Schaefli et al., 2014)

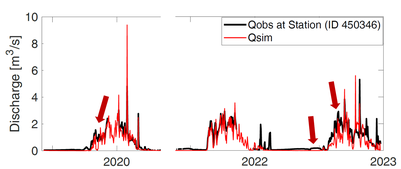

Fig. 2: Simulated and observed discharge Q of a glaciated subcatchment of the Martell river (Italy), simulated with WaSiM (Fan et al., preprint)

3) Subsurface storage might play key role ..

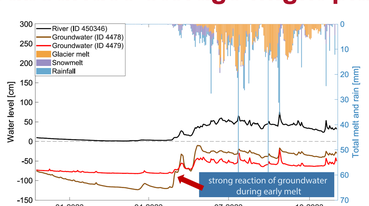

Fig. 3 : Observed discharge and shallow groundwater in the Martell valley (Italy, Fan et al., 2025), along with rainfall and simulated snow and glacier melt

.. more than snow patterns

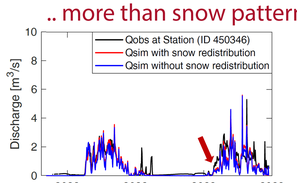

Fig. 4 : Observed and simulated discharge with and without snow redistribution, same sub-catchment as Fig. 2

4) Perceptual model from tracers

- Yearly snow-dominated discharge cycle is conditionned by subsurface storage (Fig. 9)
- Stable isotopes of water can see onset of snowmelt in groundwater (Fig. 5,7)
- Soil temperature sees snow pack insulation & frozen soil effects (Fig. 8)
- Spring & piezometer water temperature sees surface connectivity (Fig. 6)
- EC: unclear what we can learn in these environments
- *Nobel gases* (not done!): very promising --> expensive!

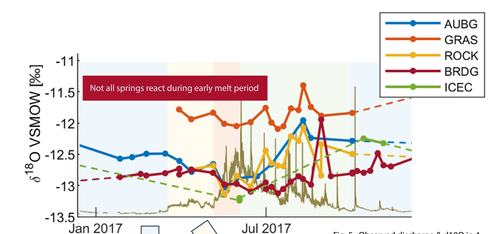

Fig. 5 : Observed discharge & d18O in 4 springs, the Vallon de Nant (CH), Michelon et al., 2023

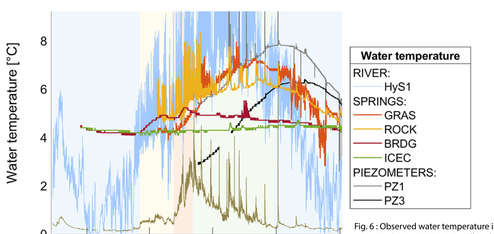

Fig. 6 : Observed water temperature in 4 springs & 2 piezometers, Vallon de Nant (CH), Michelon et al., 2023

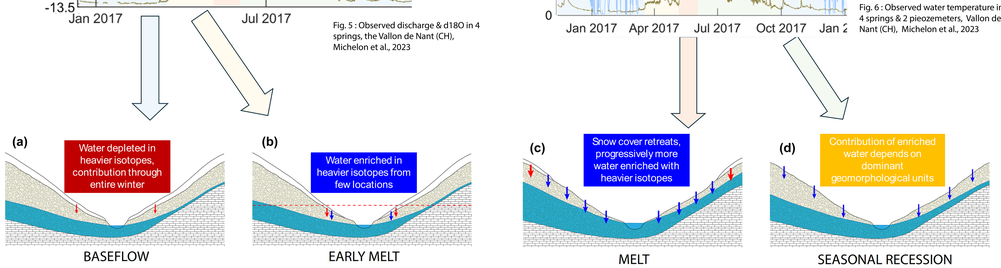

Fig. 7: Perceptual model of snow-dominated hydrological seasons (Michelon et al., 2023)

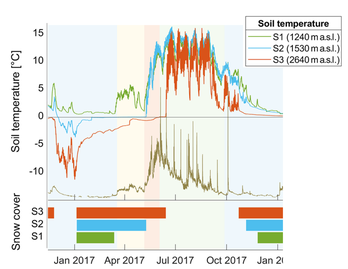

Fig. 8: Observed surface soil temperature at 3 elevations in the Vallon de Nant and snow cover duration deduced from temperature profiles (Michelon et al., 2023)

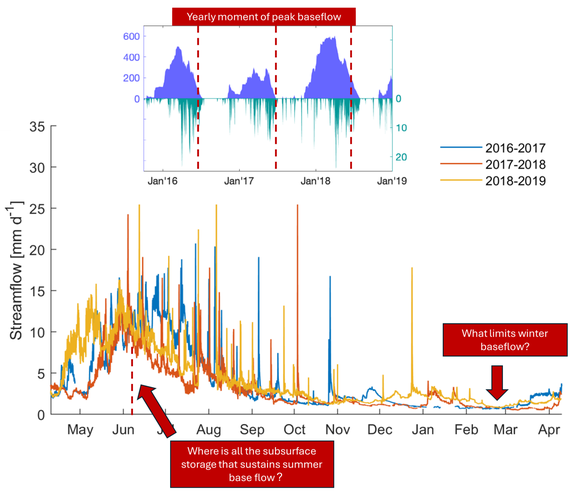

Fig. 9 : Bottom: Observed streamflow over 3 very different snow years (Michelon et al. 2023); simulated snow cover and melt for the same years (Ceperely et al., 2020), Vallon de Nant (CH), see also detailed data in https://zenodo.org/communities/vdn/

Reliable representation of future snow water resources & streamflow

Rain-on-snow

Snow line shifts

Vision:

- Represent dynamic storage states in dominant geomorphological units
- Include frozen soil processes (examples exist!) in parsimonious models
- Reliable representation of summer baseflow
- Understand winter baseflow and elevational limit (0.5 mm/d)
  - Input from ground heat melt?
  - Input from (temperate) glacier baseflow?
  - High pre-winter storage ?

Extreme inputs

Ceperley et al., 2020, Hydrol. Proc.; Fan et al., preprint 2026, HESS; Gentile et al., 2023, HESS; Michelon et al., 2021, HESS; Michelon et al. 2023, HESS; Schaefi et al., 2014, Geosci. Model Dev.