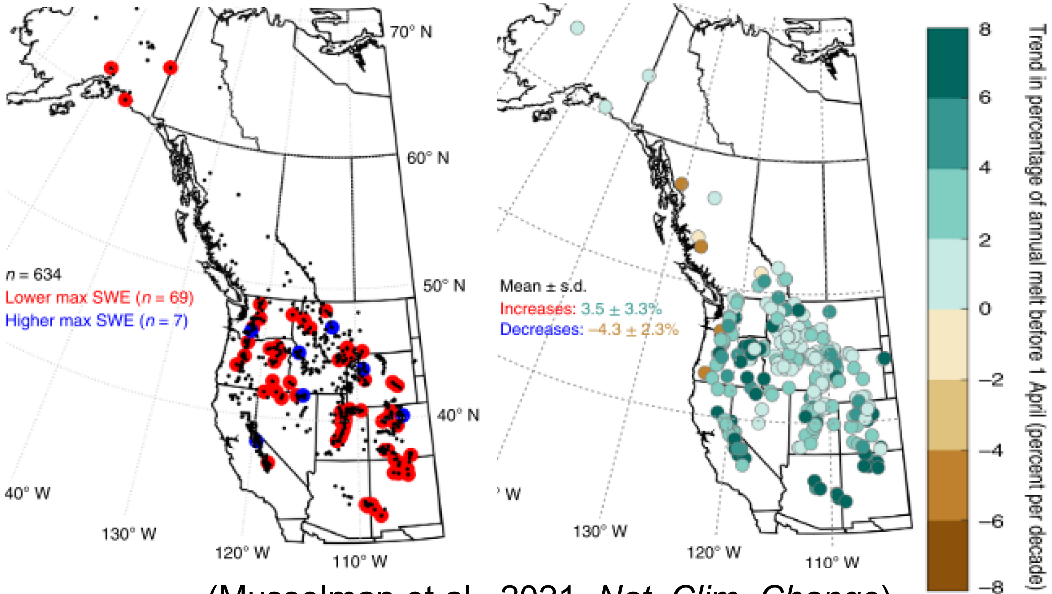
Snowmelt and groundwater in mountainous streams and plants

A modeling approach in a snow-dominated catchment

S. Kuppel, M. Sprenger, R.W.H. Carroll, C. Ulrich,
K.H. Williams & the Watershed SFA Team

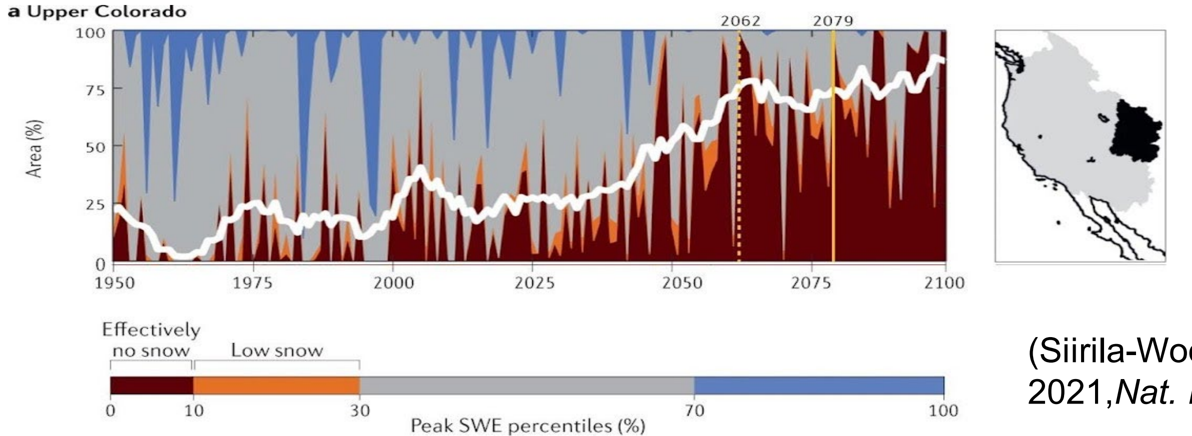
Mountainous water resources under rapid change

Snowpacks are getting **thinner** and **melting earlier**



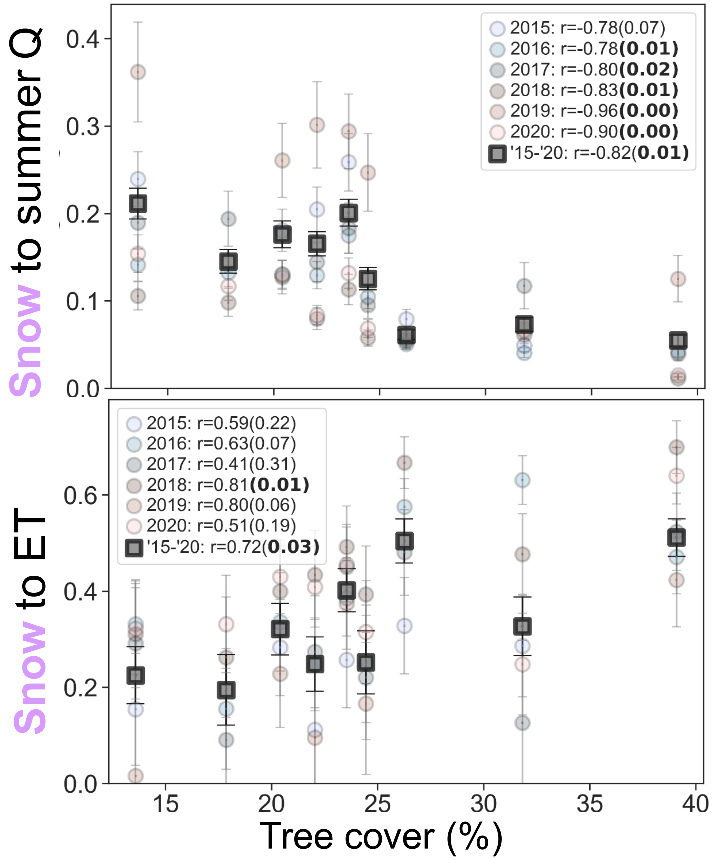
(Musselman et al., 2021, *Nat. Clim. Change*)

Transition to **low- or no-snow conditions within decades**



(Siirila-Woodburn et al., 2021, *Nat. Rev. E&E*)

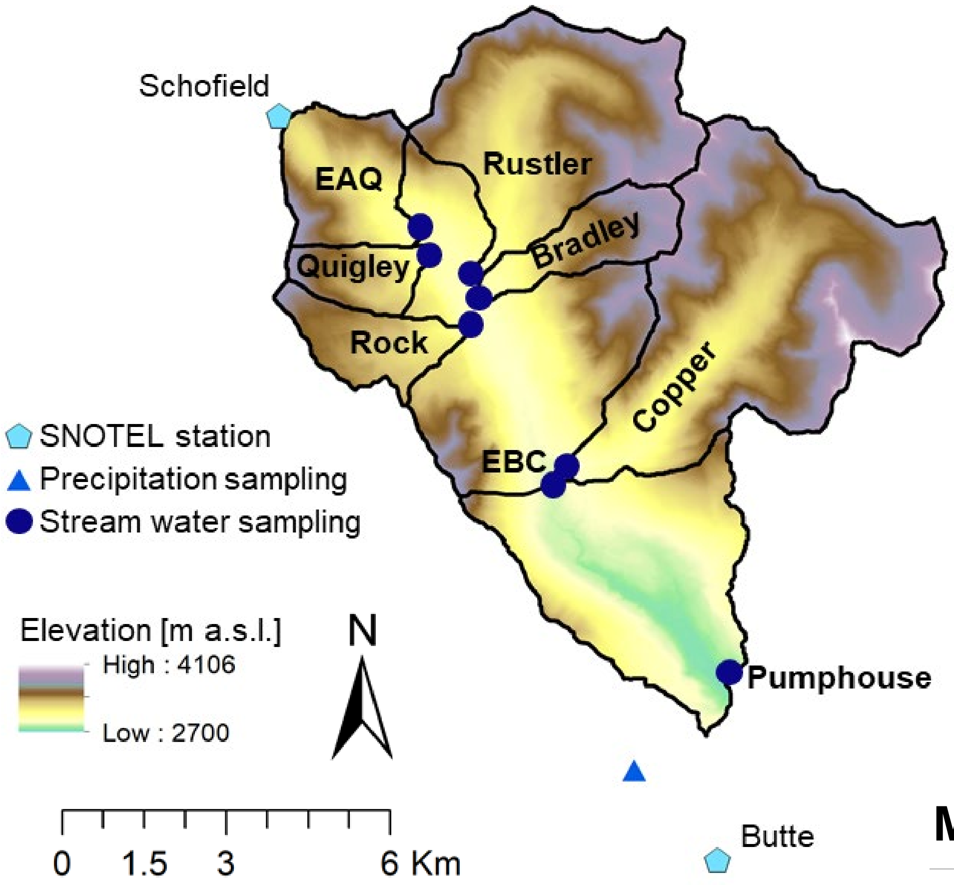
Vegetation cover is a major driver of **precipitation partitioning**



(Sprenger et al., 2022, *WRR*)

How will / do snow dynamics interplay with green water use (ET) to control groundwater recharge & streamflow?

Study site: East River Catchment



(Sprenger et al., 2022, *WRR*)

Headwaters of Colorado River
85 km^2

Snow-dominated

~80% of water input is snowfall (Oct. – May)
~20% is summer monsoon (July-Sept.)

Montane (<3000 m)
dominated by shrubs, grasses, & forbs

Subalpine (3000-3700 m)
dominated by conifer forest

Alpine (>3700 m)
above treeline

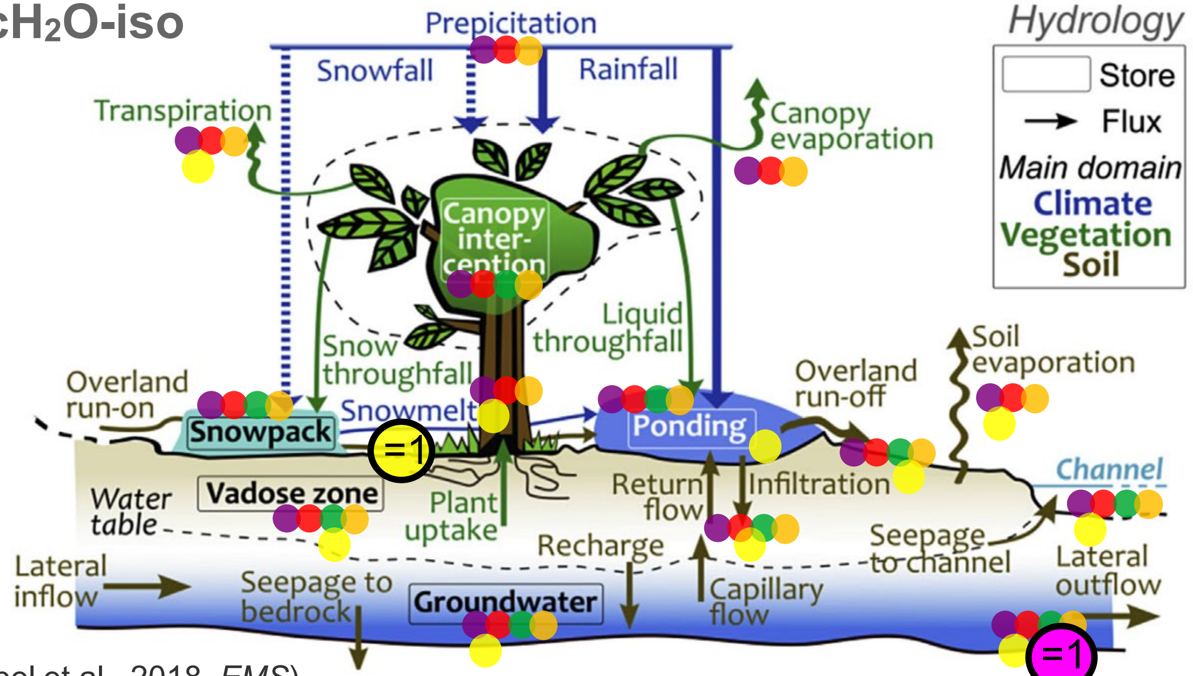
Multiple data sets

- **Discharge** (several outlets)
- **Snowpack** (SNOTEL sites)
- **Energy balance** (latent heat evaporation, sensible heat) & **ET** @ eddy covariance tower
- **Groundwater levels**
- **Soil moisture**
- **Stable isotopes** (stream water, precipitation, snowpack snowmelt, groundwater, soil, plant xylem)

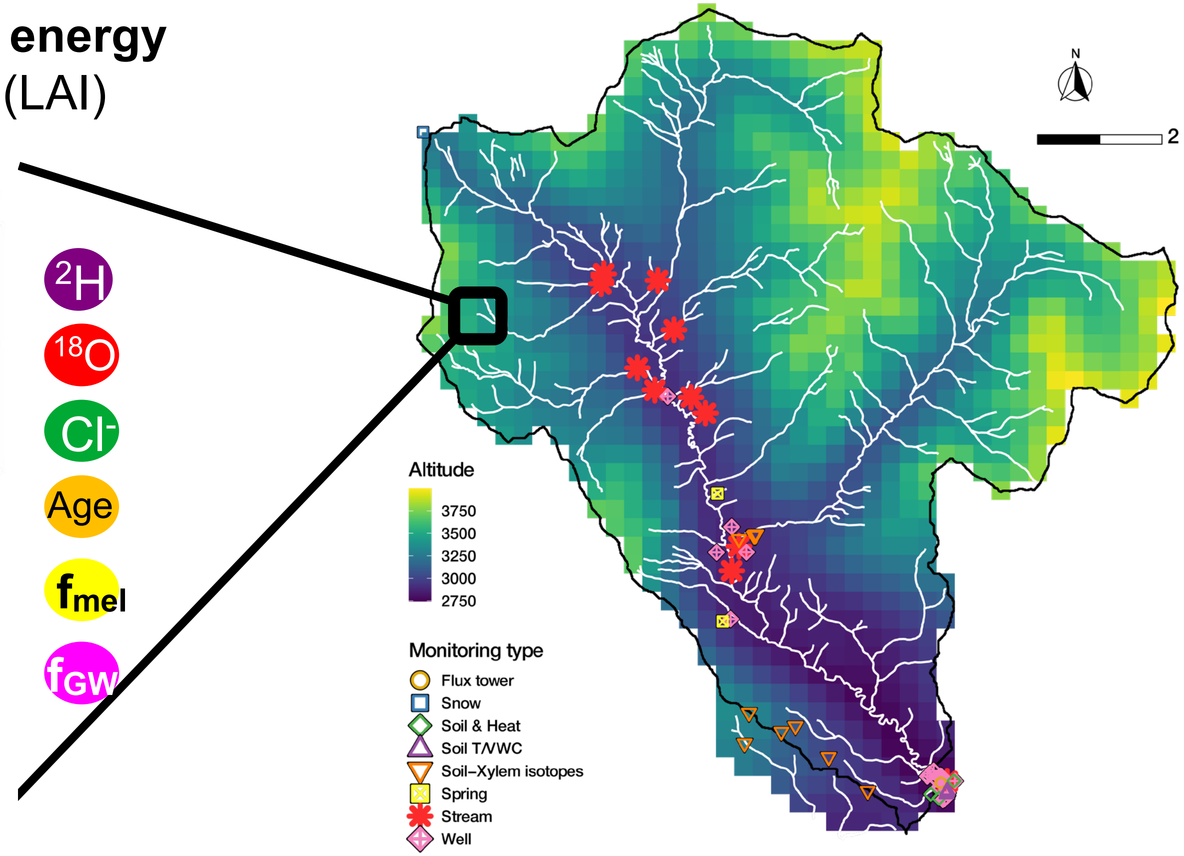
Modelling ecohydrological fluxes, stores & tracers

◆**Spatially-distributed modelling** coupling process-based **energy balance & 3D water routing** with forced plant phenology (LAI)

EcH$_2$O-iso



(Kuppel et al., 2018, *EMS*)



- Flux-store **tracking of stable isotopes**, water ages & chloride (full mixing in sub-timestep between pixel-scale compartments)

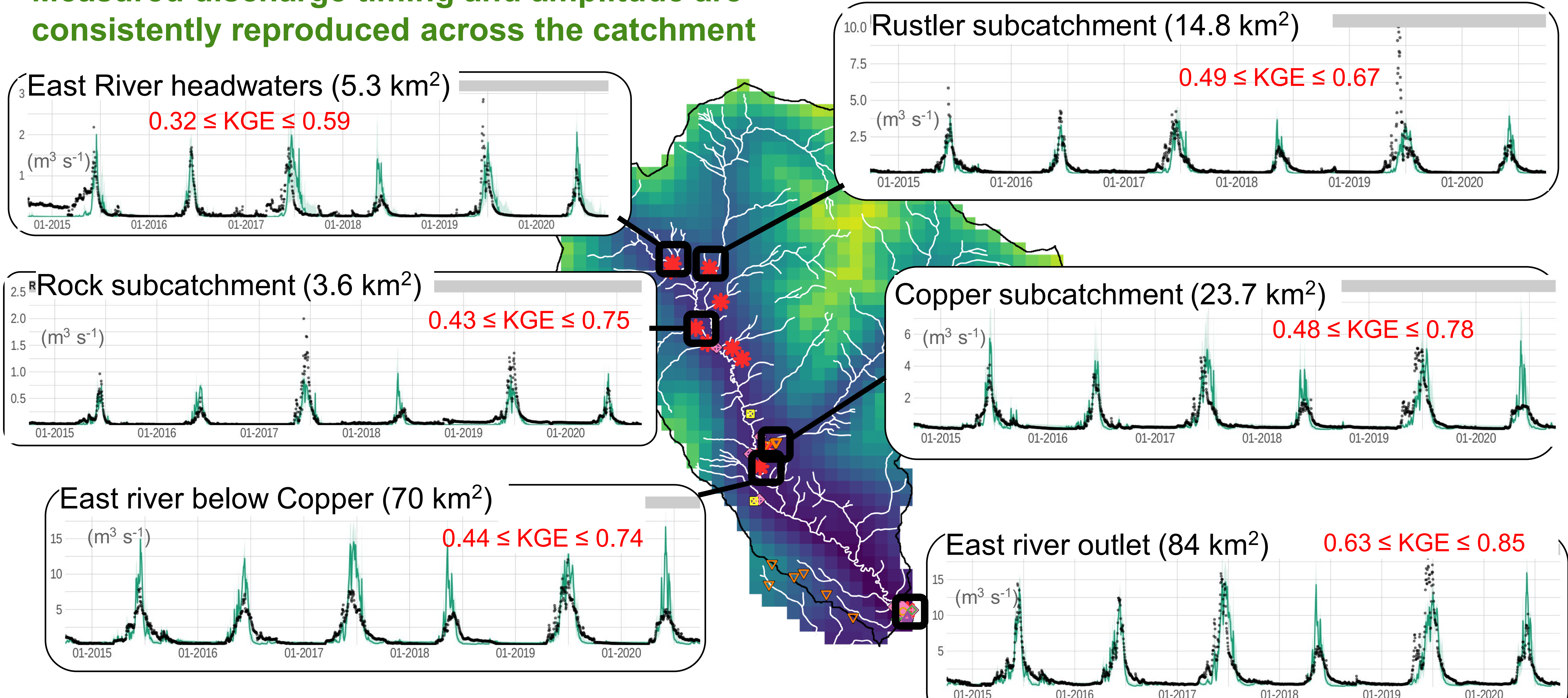
(Kuppel et al., 2018, *GMD* ; Douinot et al., 2019, *HP*)

- New **virtual tracers** of **snowmelt** & **lateral GW** fluxes

- **300m**-cell and **daily** steps **(2014-2020)** in **100m-deep domain**
- **Multi-objective calibration** fitting **20 non-isotopic datasets** (74 parameters, Monte Carlo / LHS sampling, rank-based KGE)
- **30 "best" simulations** used for evaluation and analysis

Simulations of discharge across the catchment

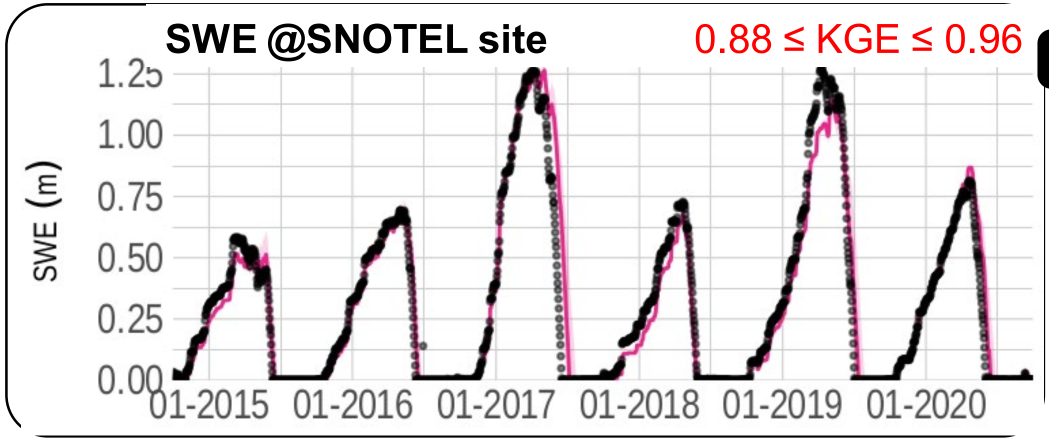
Measured discharge timing and amplitude are consistently reproduced across the catchment

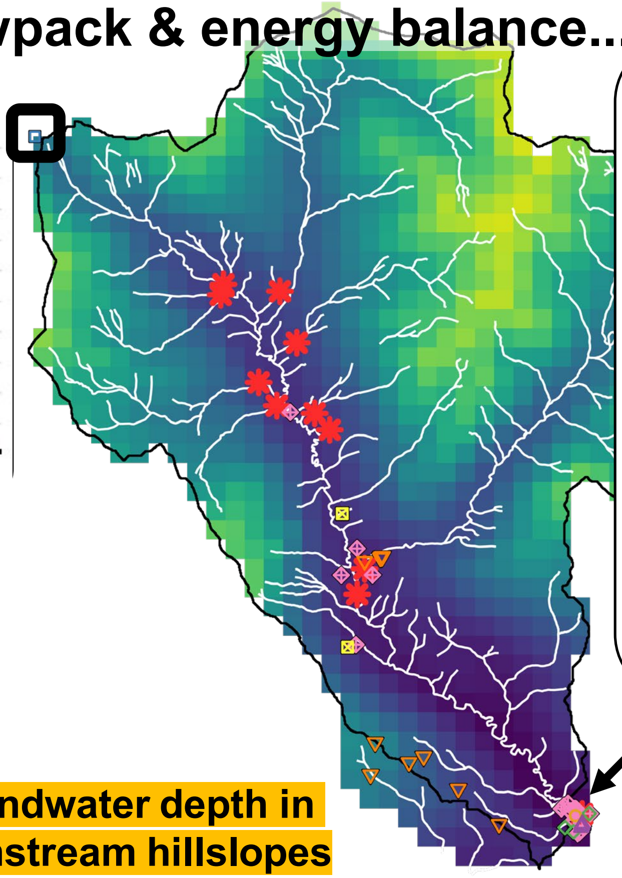


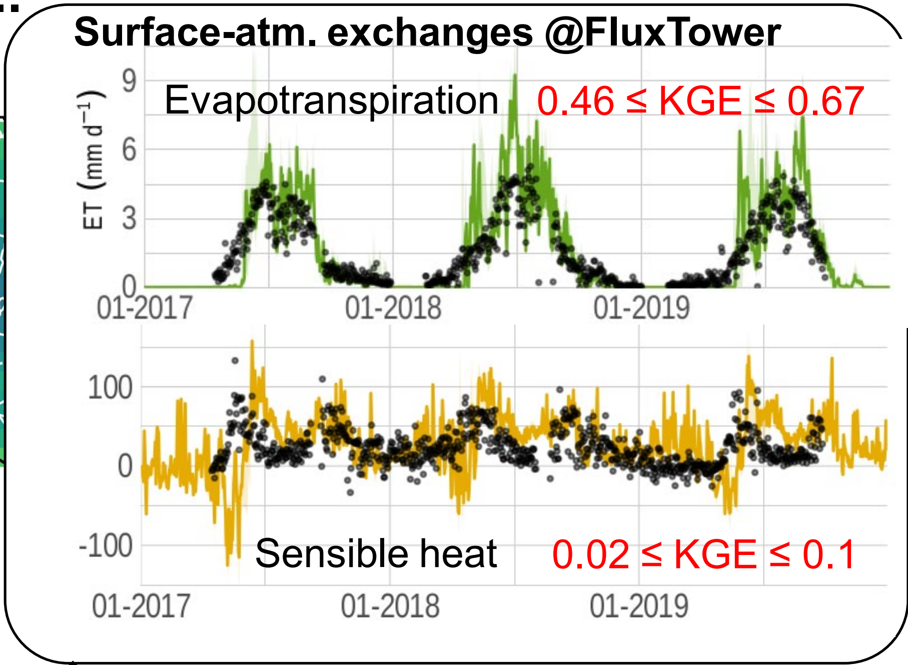
Data / **Simulations** (median & 80% envelope, 30 reference runs)

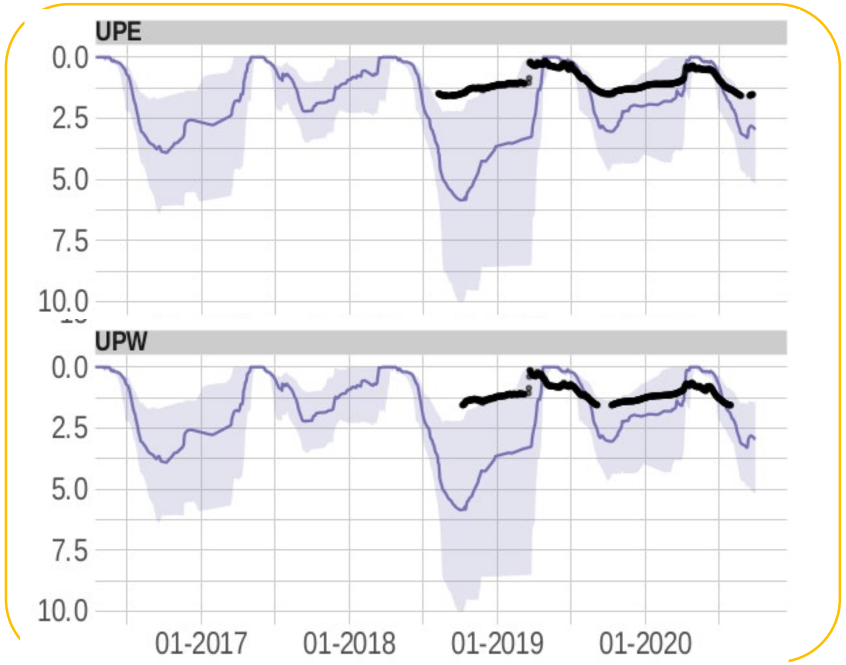
Simulations of other water & energy components

Consistent discharge from robust snowpack & energy balance...



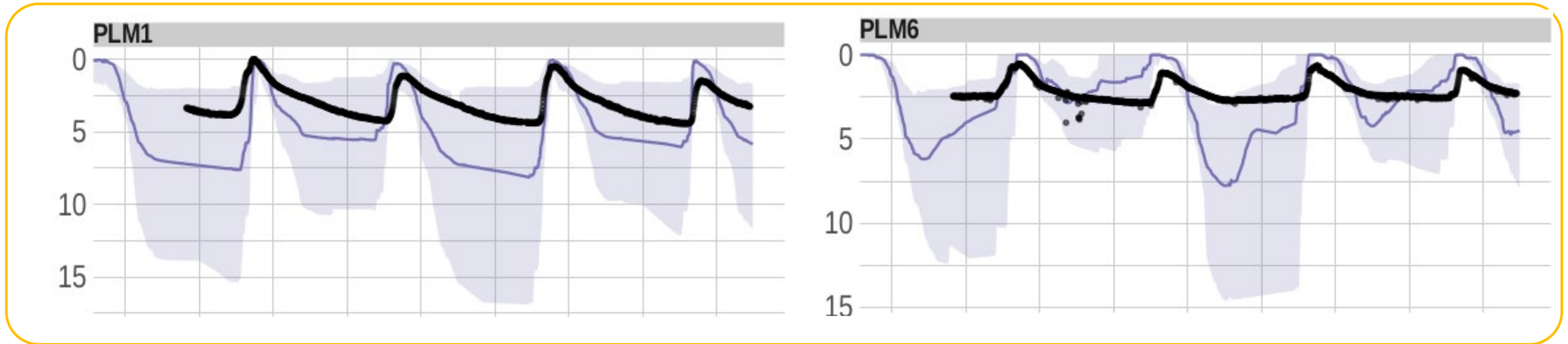






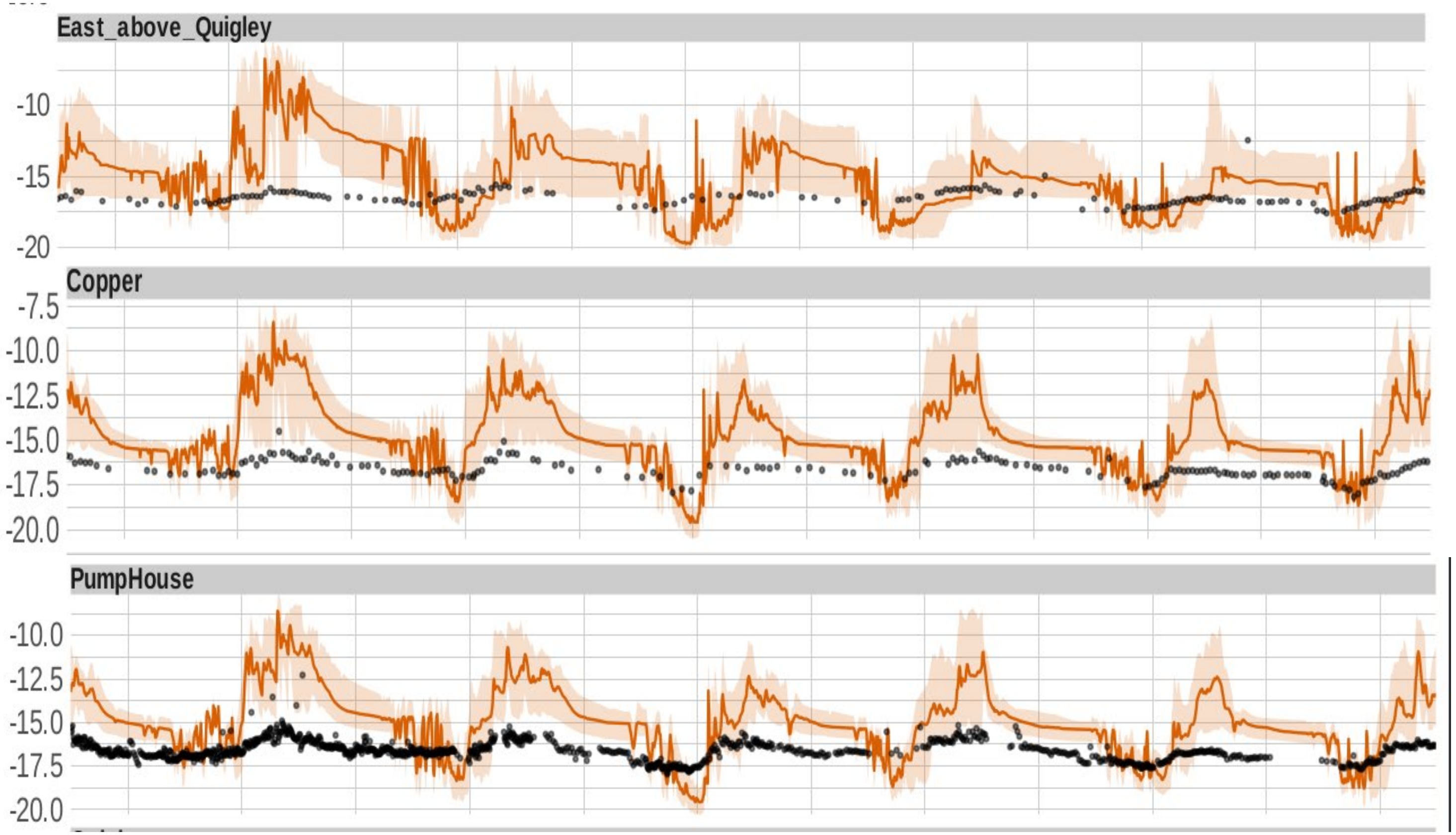
Groundwater depth in downstream hillslopes

...but groundwater dynamics are overestimated

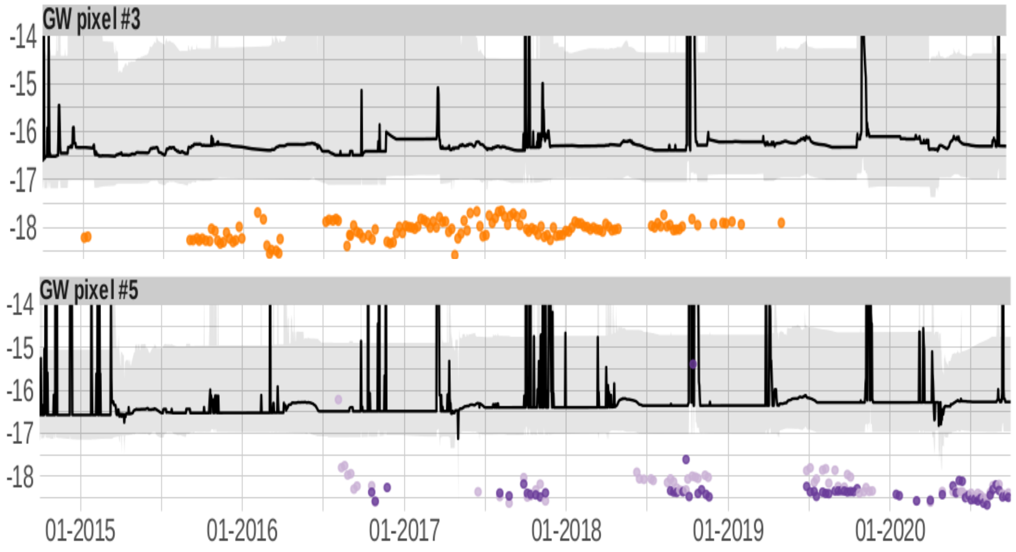


Less of model-data agreement for tracers!

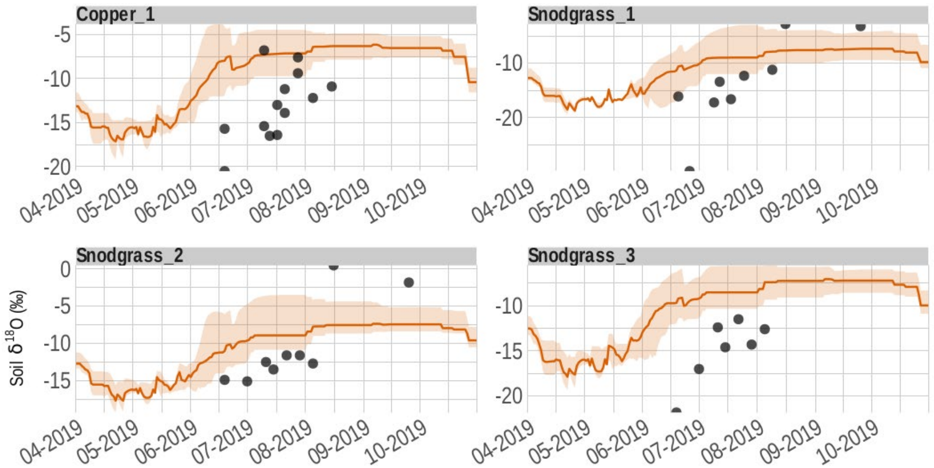
δ18O in stream water (‰)



δ18O in groundwater (‰)



δ18O in topsoil (‰)

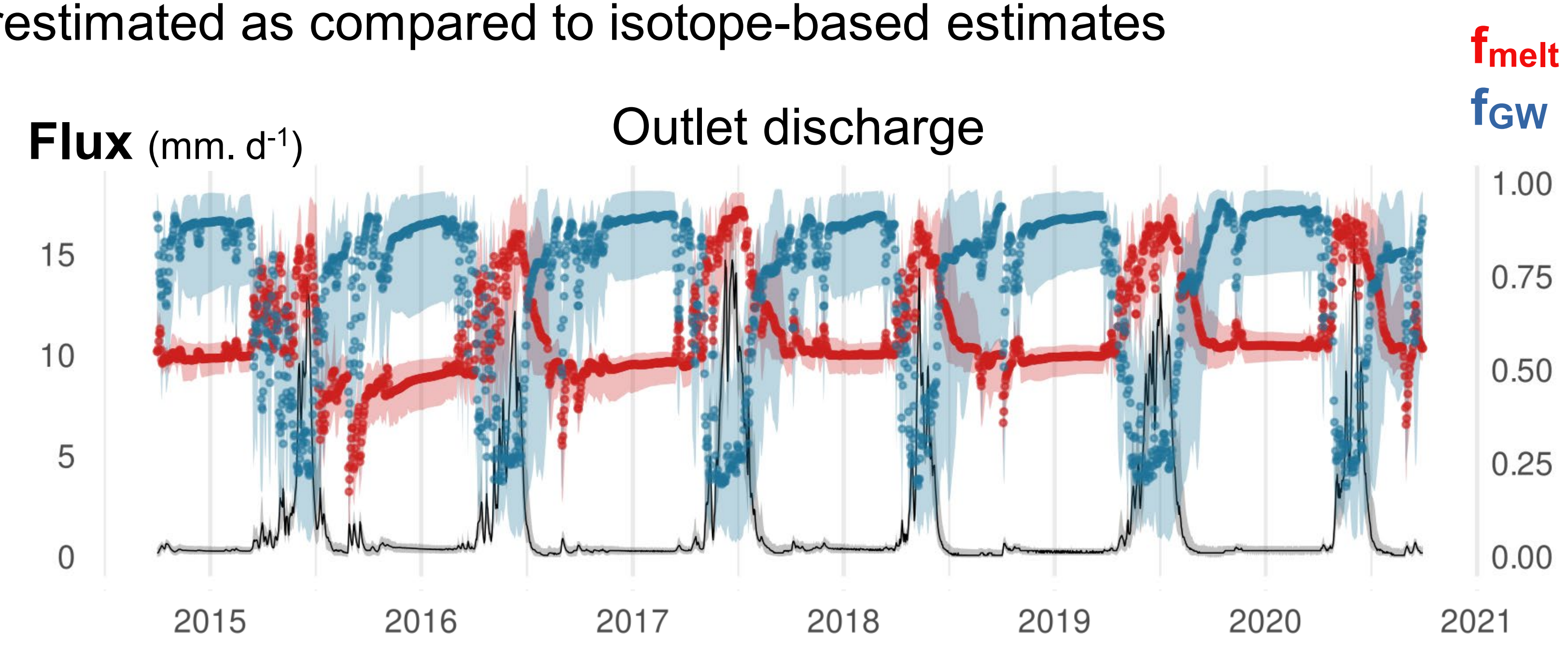


Overestimated d18O range in simulated stream water
→ overenriched groundwater in baseflow?
→ overestimated snowmelt runoff in spring
+ underestimated baseflow?

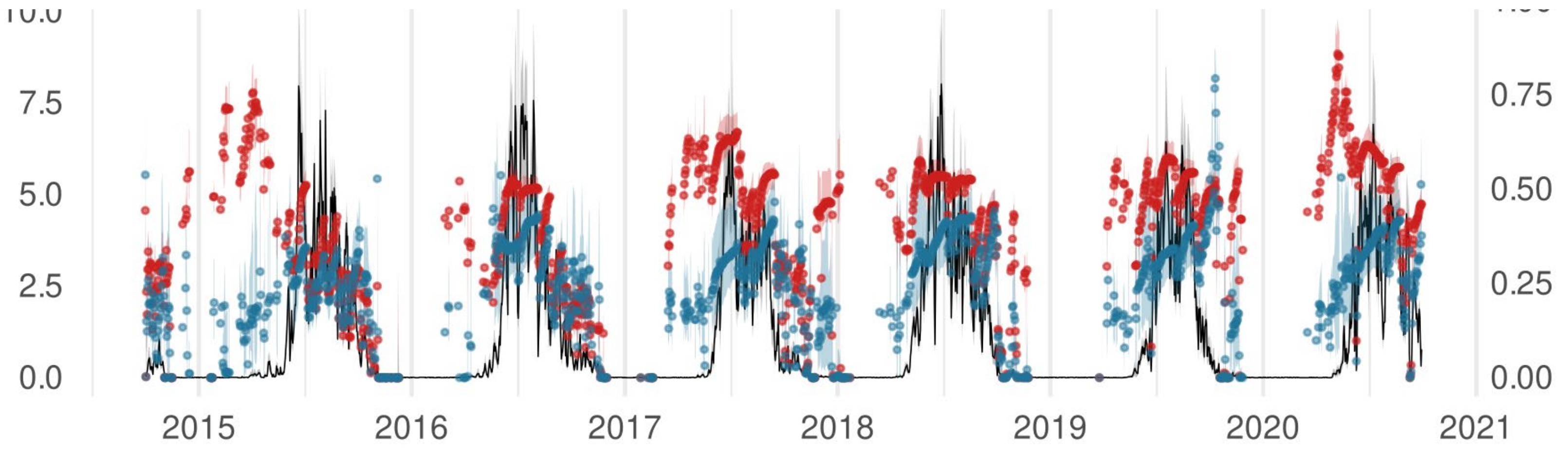
Snowmelt & groundwater origins in catchment outputs

Only half (52-54%) **of GW** storage
from snowmelt recharge→ underestimated as compared to isotope-based estimates

Outlet discharge budget
68-84% from **snowmelt origin**
21-62% from **groundwater flow**



Evapotranspiration budget
44-50% from **snowmelt origin**
25-42% from **groundwater flow**



Summary

- **Interplay of snowpack dynamics & green water use (ET) on GW recharge & streamflow** using tracer-enabled spatially-distributed modelling

Model calibrated using numerous hydrometric ecohydrological showed:

- **#1 Discharge, snowmelt & surface-atmosphere exchanges consistently captured** (timing and amplitude) **across the catchment**
  #2 Groundwater depth dynamics overestimated
- Validation with tracer data
- **#3 Overestimated stream water $d^{18}O$ dynamics** (base flow enrichment → high-flow depletion)

- Likely **underestimation of snowmelt infiltration** & **overestimation of rainfall contributions to runoff**
- **Confirmed by first glance at virtual tracers** ← direct access to partitioning

→ **Further work needed!!**

POSTDOC POSITION (2 years)

Deep critical zone contribution to nutrient budgets in 3 tropical environments

(pristine forest, irrigated agriculture, agroforestry)

Géosciences Environnement Toulouse (France)

Indian Institute of Science (Bangalore, India)

contact: jean.riotte@ird.fr