Modelling streamflow to get insights about catchment characteristics

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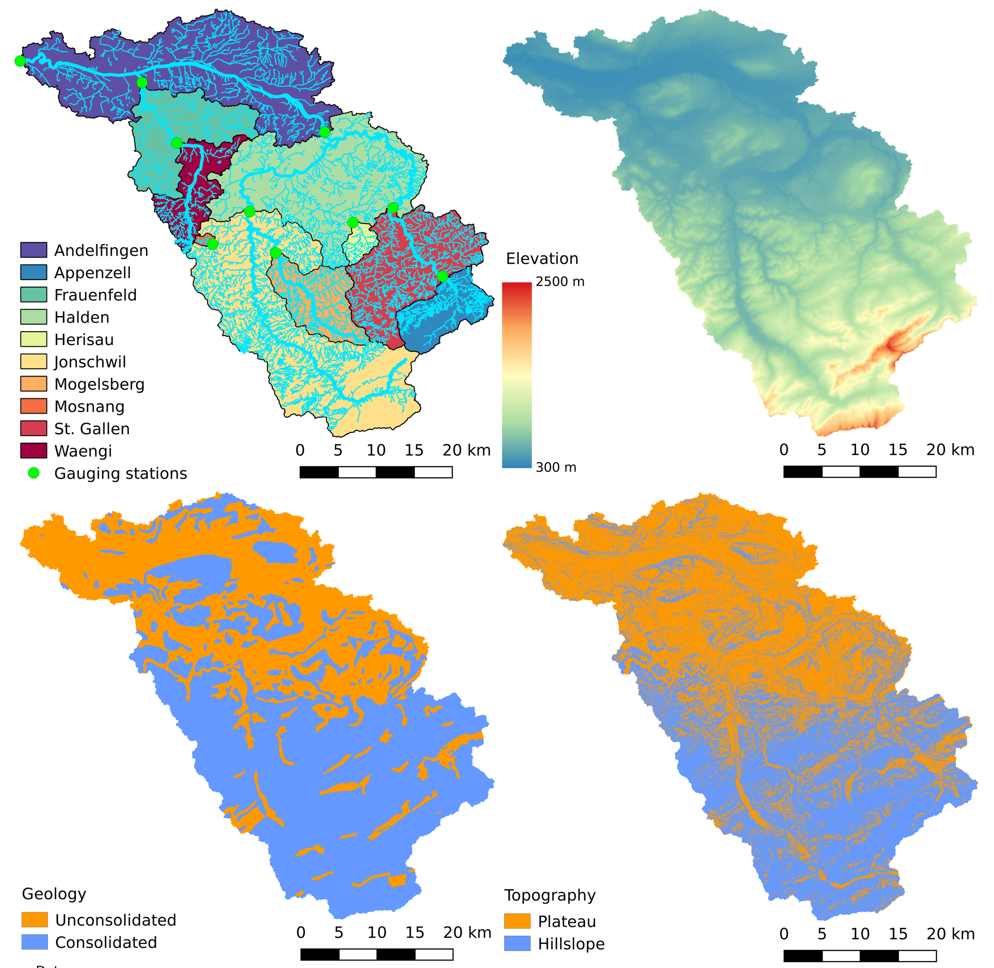
Research objectives

- What causes streamflow variability? How much is it caused by climate variability? How much is it caused by catchment proprieties (e.g. geology vs topography)?
- Does a distributed model improve the performance compared with a lumped model?
- Is more effective distributing the states or the properties?

Study area

The Thur is an alpine and peri-alpine catchment in the north-east of Switzerland and it is characterized by a large spatial variability in terms of climatic conditions and physical characteristics.



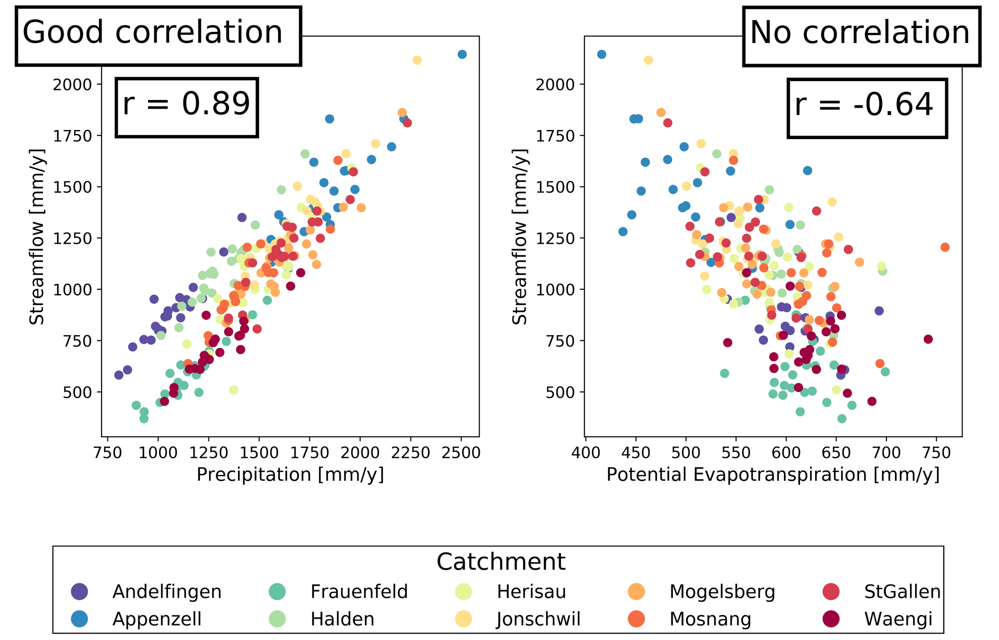
Data source:
Elevation + Geology: swisstopo (2015), swissAlti3D, Geology500; DV 5704 000 000, reproduced by permission of swisstopo / JA100119.
Catchment: BAFU (2012), Einzugsgebietsgliederung Schweiz EZGG-CH, Bundesamt für Umwelt (BAFU), CH-3003 Bern

Data analysis

Streamflow vs Meteorological variables

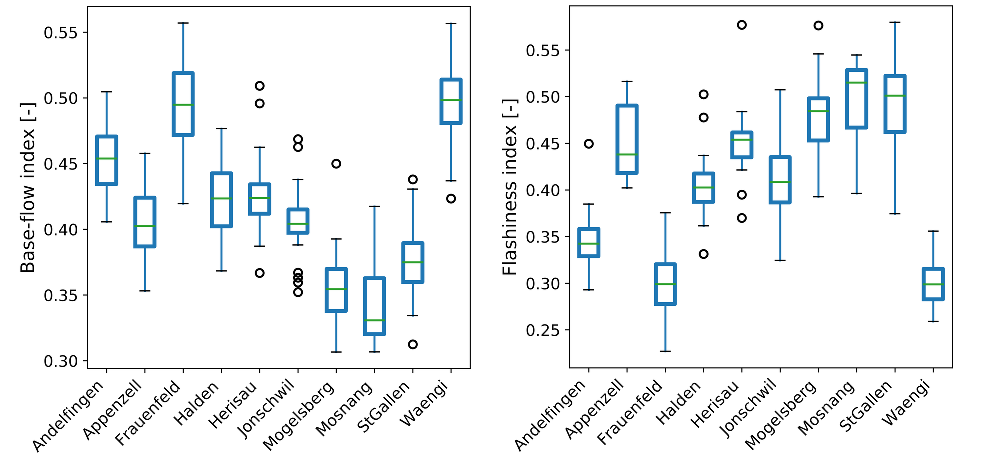
Precipitation and streamflow data shows a strong variability between the catchments and a good correlation (Pearson's r equal to 0.89).

There is no visible correlation between streamflow and potential evapotranspiration.



Signatures

The signatures vary strongly between catchments reflecting their different behaviour.



$$BFI = \frac{\sum_{t=1}^{N} Q_t^{(b)}}{\sum_{t=1}^{N} Q_t} \qquad FI = \frac{\sum_{t=2}^{N} |Q_t - Q_{t-1}|}{\sum_{t=2}^{N} Q_t}$$

$$Q_t^{(b)} = min\left(Q_t; \theta_b Q_{t-1}^{(b)} + \frac{1-\theta_b}{2}(Q_{t-1} + Q_t)\right)$$

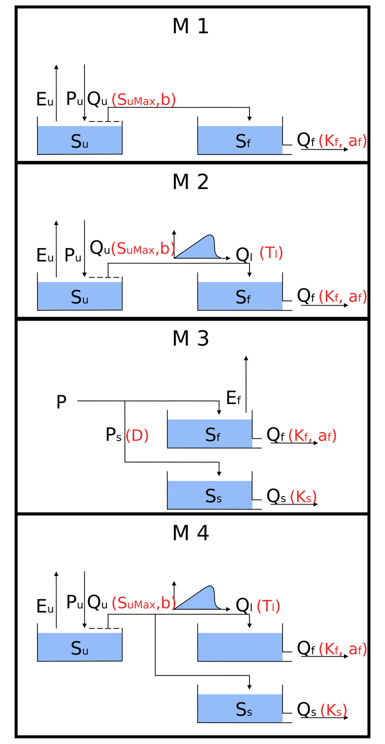
Model

Lumped and distributed models

We compared the performance of 4 model structures (generated with SUPERFLEX, Fenicia et al, 2011).

All the structures have a snow reservoir that is not shown in the schemes.

The models were first applied with spatially uniform parameters (using lumped and distributed states). The best performing model (M 4) was then applied with spatially distributed parameters.



Residual error model

In order to describe uncertainties, we assumed:

$$Z[Q_{obs}] = Z[Q_{sim}] + error$$

where Z is the Box-Cox transformation, with λ = 0.5

$$Z[x] = \frac{x^\lambda - 1}{\lambda}$$

and the error is assumed to be normally distributed with zero mean and constant (calibrated) variance.

Inference scheme

The model parameters are calibrated to observed data using a Bayesian inference approach

$$P(\theta|X,Q) \approx P(Q|X,\theta)P(\theta)$$

(Posterior: $P(\theta|X,Q)$; Likelihood: $P(Q|X,\theta)$; Prior: $P(\theta)$)

Depending on the simulation, the model is calibrated in the single gauging station or in all the stations together.

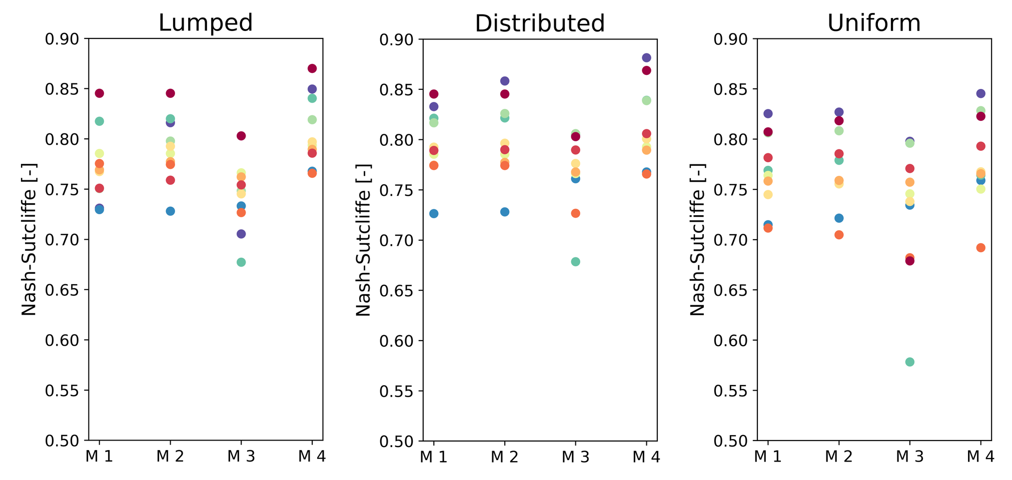
A calibration-validation in time scheme has been used. All the plots displayed in the poster are validation results.

Model configuration

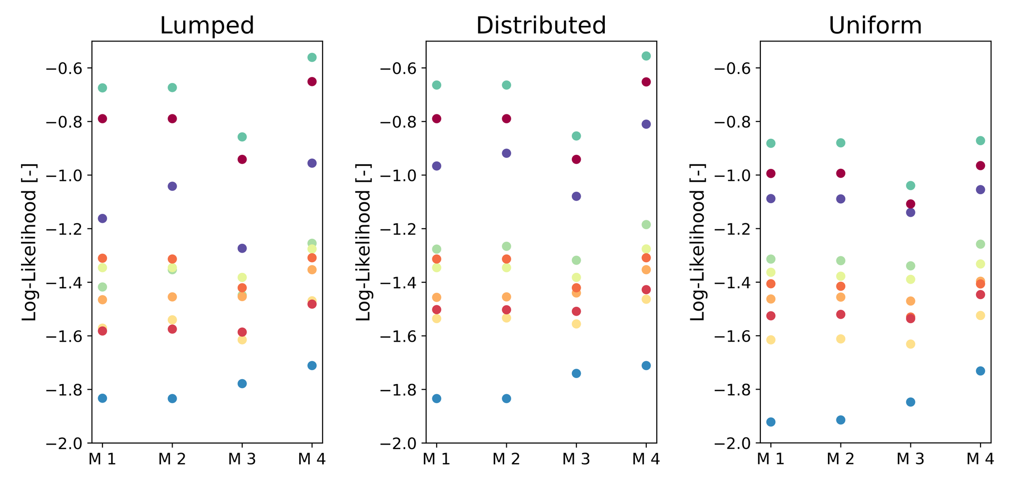
Model name	Input	Calibration	HRU
Lumped	Lumped	Single catchment	1
Distributed	Per catchment	Single catchment	1
Uniform	Per catchment	All catchments	1
Geo	Per catchment	All catchments	2 - geology
Topo	Per catchment	All catchments	2 - topography

Uniform parameters

Nash - Sutcliffe efficiency



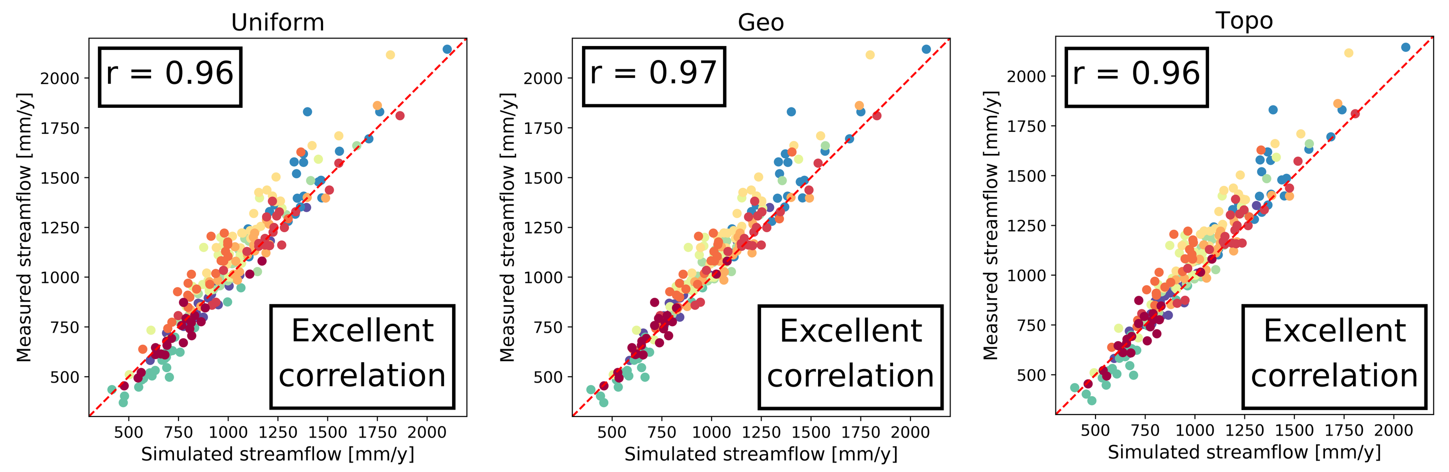
Log-Likelihood



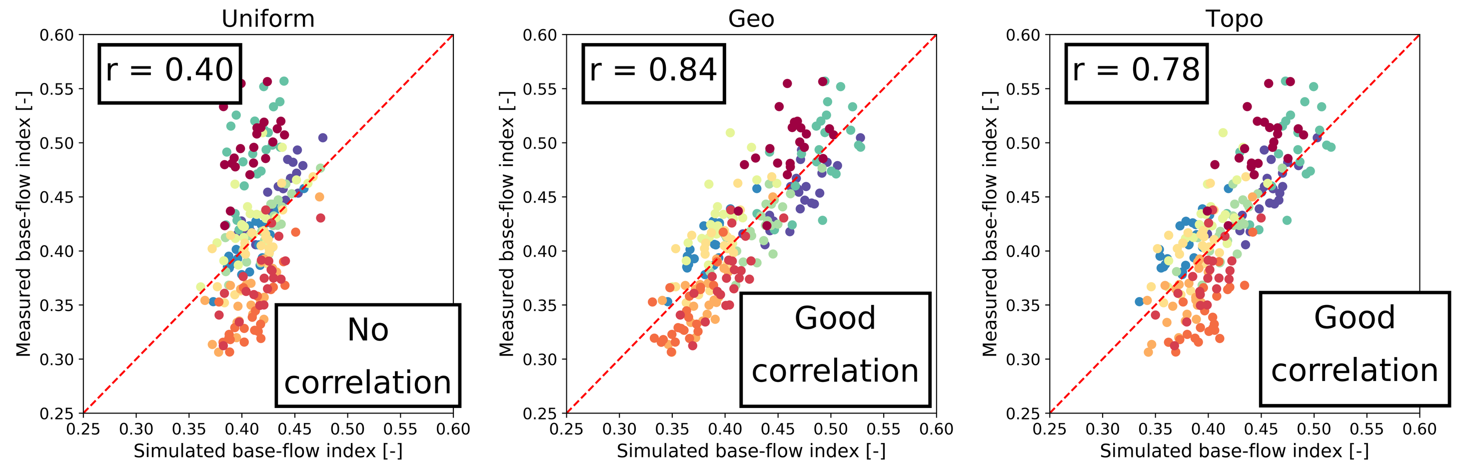
In all the configurations, the best performing model structure is M 4. This was used for subsequent analyses with distributed parameters.

Distributed vs uniform parameters

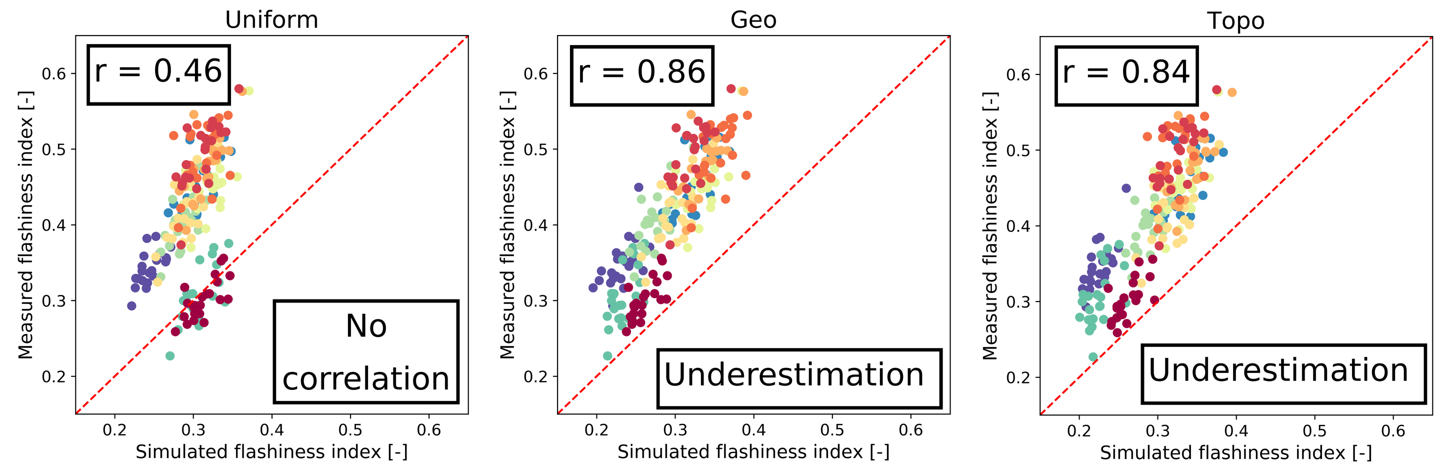
Simulated vs measured streamflow



Simulated vs measured baseflow index



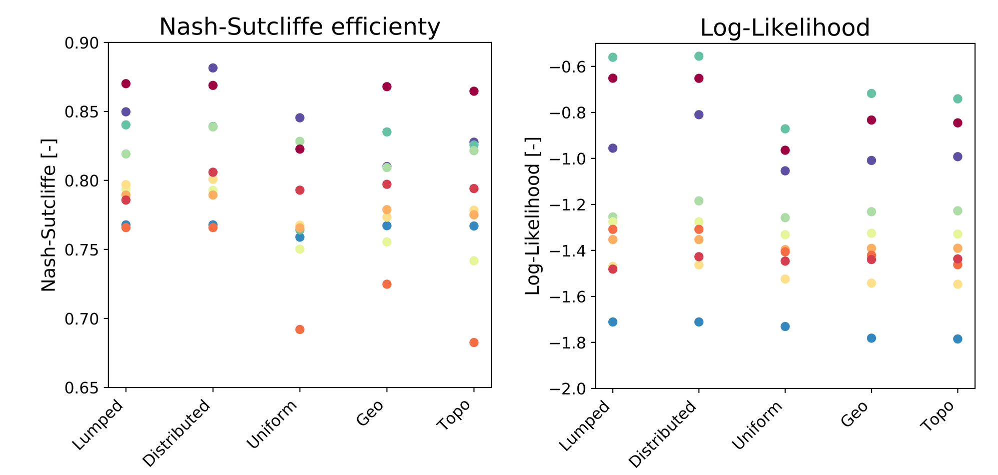
Simulated vs measured flashiness index



Distributing the states ensures an excellent representation of the water balance but only distributing the parameters gives a good correlation of the signatures. There is an underestimation of the flashiness index probably due to limitations in the likelihood.

Conclusions

Best performance of the different configurations



What we have learnt

- Distributing the inputs and the states improves the performance of the model in terms of Nash-Sutcliffe and Likelihood.
- Distributing the proprieties of the catchment in different HRUs improves the representation of the signatures.
- Distributing topography vs geology leads to similar results, which is not totally unexpected, as their relative areas in the subcatchments are similar.

What's next?

- Use other catchment properties to define the HRUs (soil, groundwater resources, land cover, etc.).
- Improve the snow representation.
- Analyze the simulated hydrograph in detail to spot model weakness.

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Reference

Fenicia, F., D. Kavetski, and H. H. G. Savenije (2011), Elements of a flexible approach for conceptual hydrological modeling: 1. Motivation and theoretical development, Water Resources Research, 47(11), W11510