session HS2.2.1
Models and Data: Understanding and representing spatio-temporal dynamics of hydrological processes
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Diagnostic of a regional distributed hydrological model through hydrological signatures

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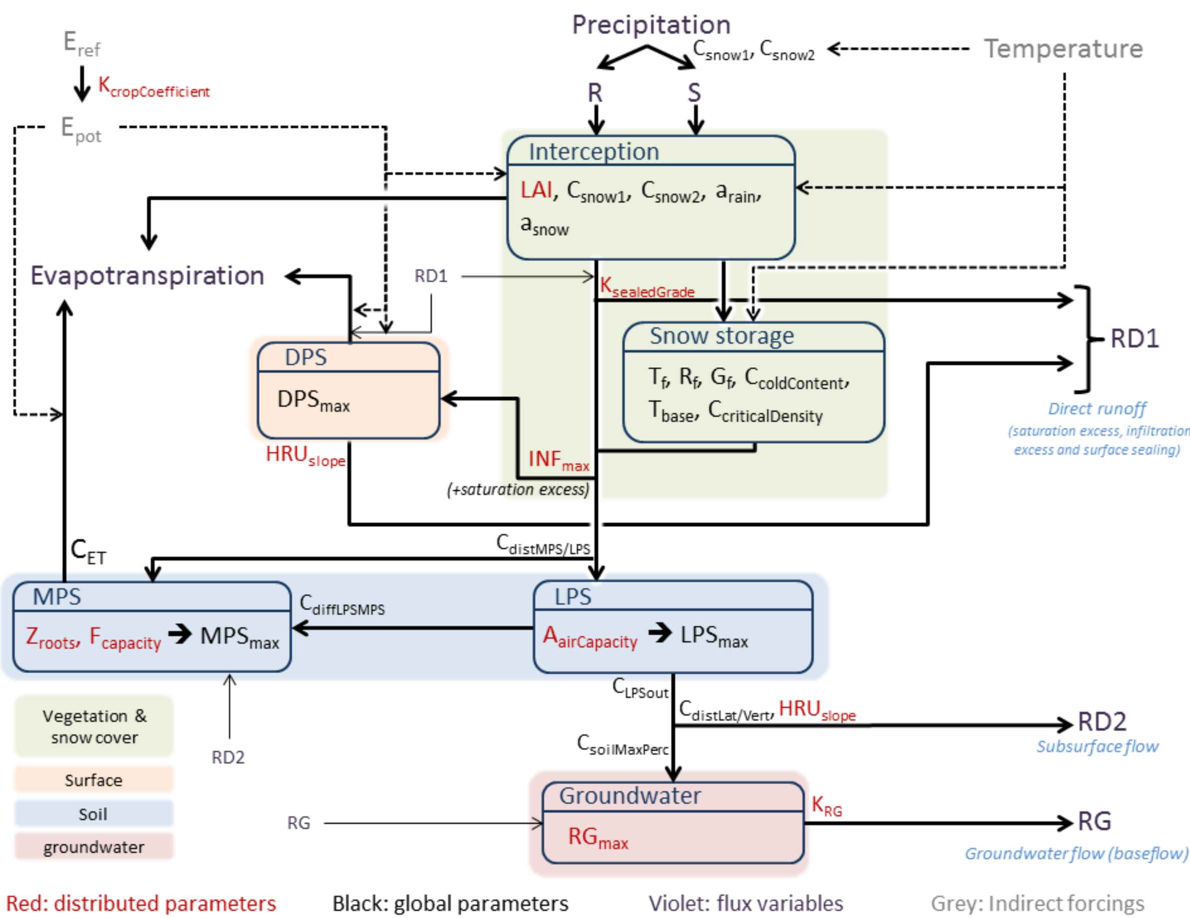
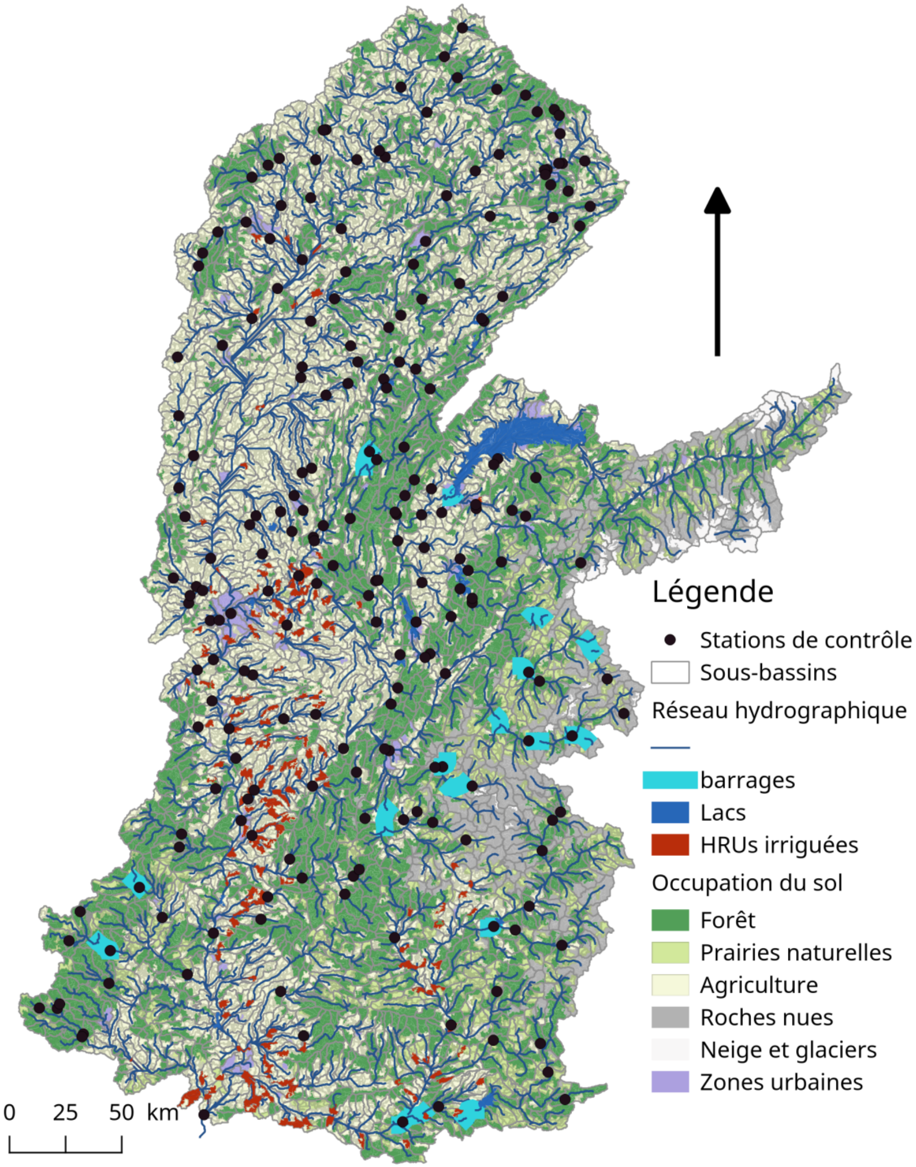
Context: distributed hydrological modelling at regional scale



Structure & parameters of the J2000 model (Horner, 2020)

- Distributed models are useful for process-based assessment of water resources under global change
- But…
- Complex models with a high number of parameters
- Large catchments (~ 100 000 km² and more) with high spatial heretogeneity : climate, topography, geology, land use…
- Model setup and parameterization is a complex task

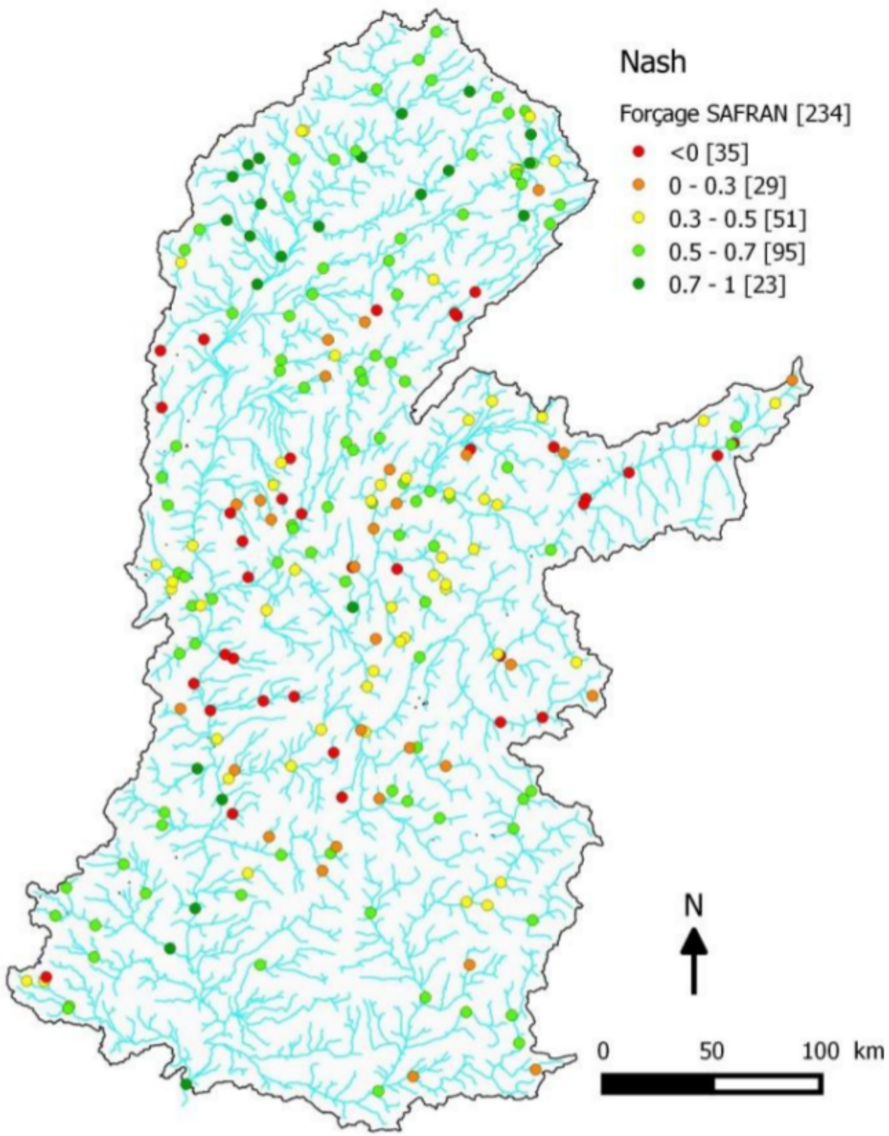
Our case study : J2000-Rhône



- Distributed model of the Rhône catchment in France and Switzerland (100 000 km²)
- Based on the J2000 distributed model
- Takes into account dam management, irrigation and drinking water
- Parameterization strategy :
  - In situ measurements / previous studies
  - 234 control stations for Qobs / Qsim comparison
  - Manual parameter tuning on a few elementary subcatchments
  - Manual regionalization based on geology / land use / climate

Branger et al., 2018 ; Krause et al., 2006

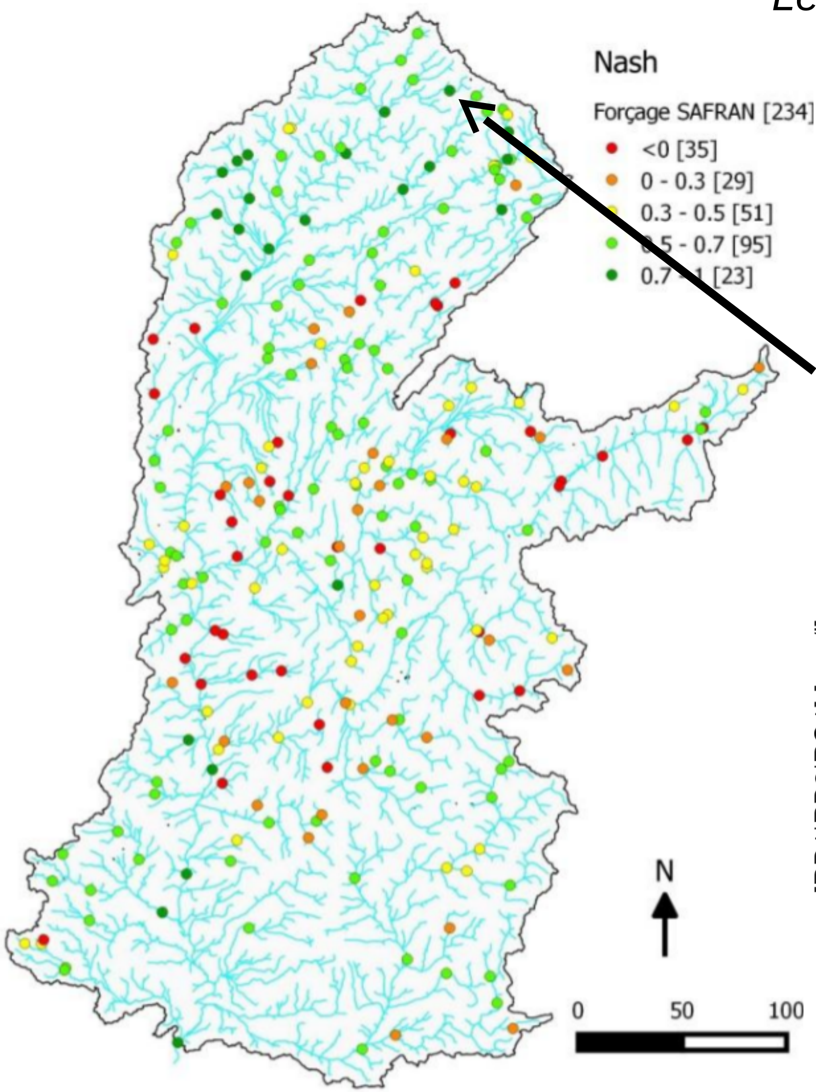
Model performance evaluation

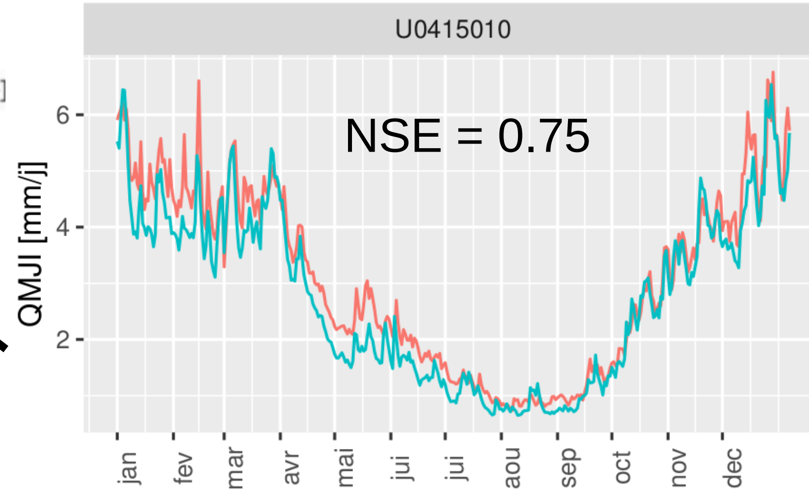


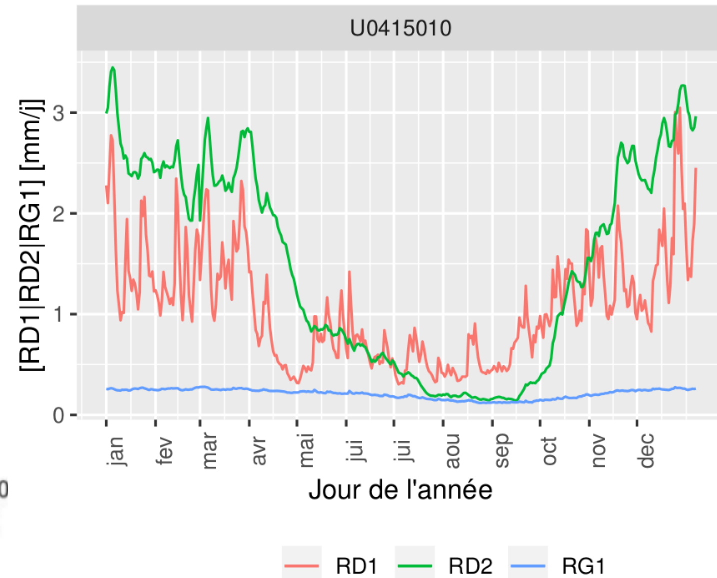
- Simulations
  - Natural hydrology
  - SAFRAN meteorological forcing (Vidal et al., 2010)
  - Period 1981-2010
- Still a lot of stations with unacceptable NSE values
- Manual parameterisation strategy has limitations

The right answers for the right reasons ?

Le Breuchin à la Proiselière-et-Langle (123 km2)







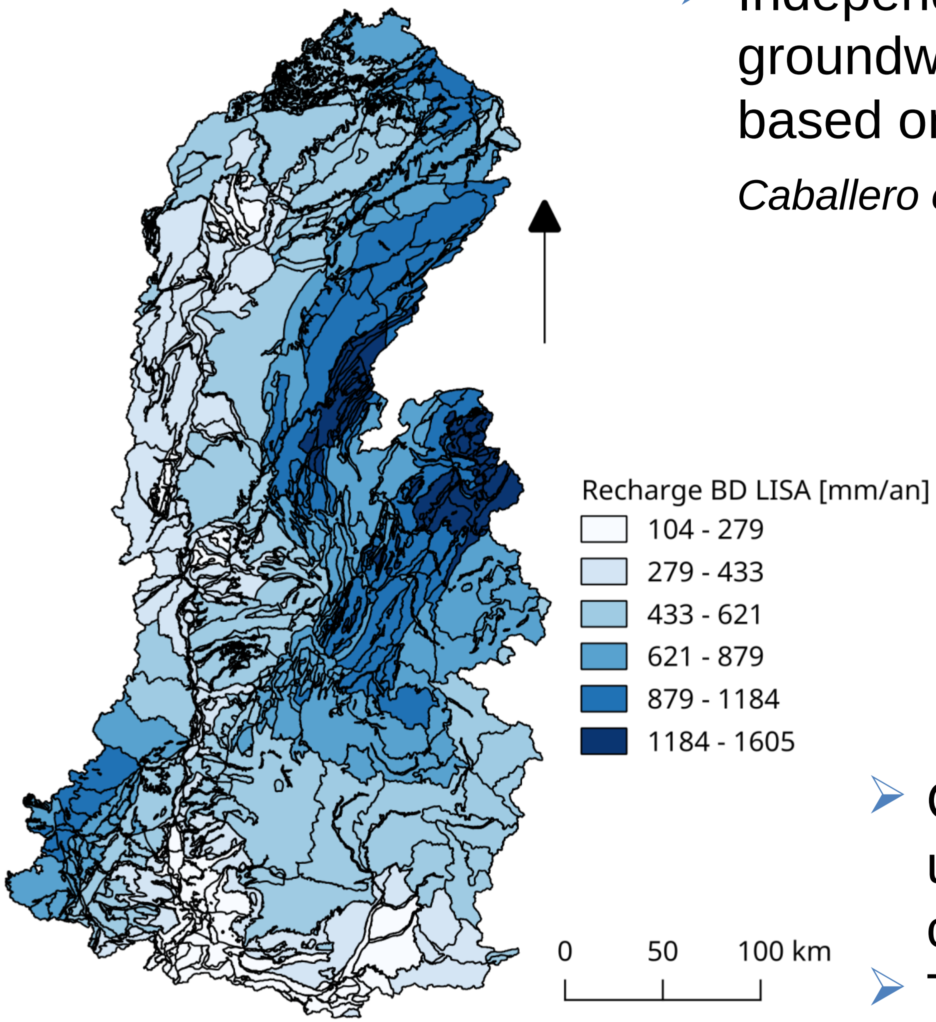
Simulated groundwater component (RG1) is unrealistically low and steady

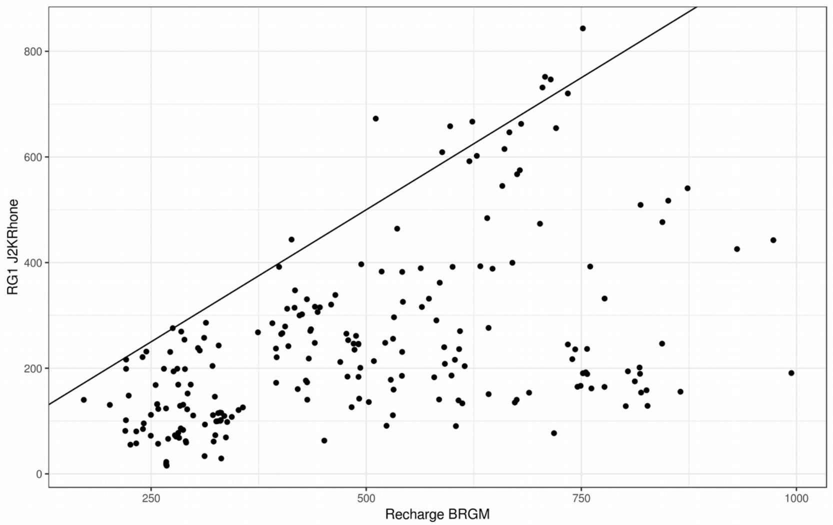
- **Good agreement Qsim/ Qobs can also hide misunderstanding of hydrological processes**

Comparison of groundwater recharge estimates

- Independant calculations of mean annual groundwater recharge calculated by BRGM based on BDLISA hydrogeology maps

Caballero et al. (2016)





- Comparison with J2000 RG1 : strong underestimation over the whole catchment
- There might be a problem with the representation of groundwater processes in the model !

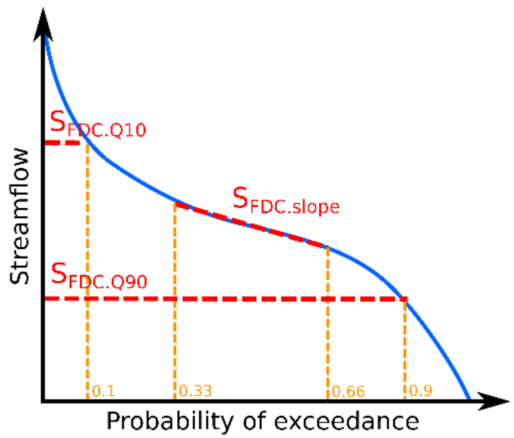
Our diagnostic approach methodology

- Need to improve the performance of the model for the good reasons = better understanding and reproduction of hydrological processes, even at large scale
- Development of a diagnostic approach through hydrological signatures (Gupta et al., 2008)
  - Gives direction for model improvement
- Set of 11 hydrological signatures based on rainfall / runoff data (Horner, 2020 ; Horner et al., in prep)

Type of analysis	***Signatures***
Runoff coefficient	RC = Q/P
Flow duration curve (FDC)	Mid-segment slope, quantiles Q0.1, Q0.9
Baseflow analysis	BFI, baseflow magnitude
Seasonal P-Q threshold	Breakpoint, P-Q slopes in dry / wet periods
Streamflow recessions	Early / late recession characteristic times tau1, tau2

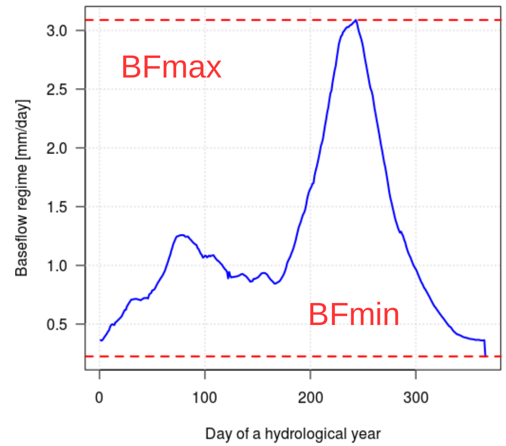
Hydrological signatures

Flow duration curve (FDC)



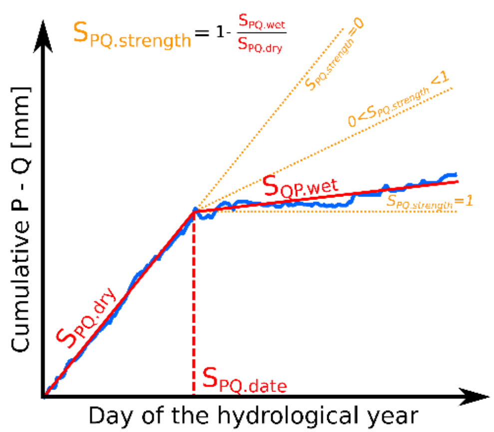
Baseflow analysis

Baseflow extraction with Gustard algorithm

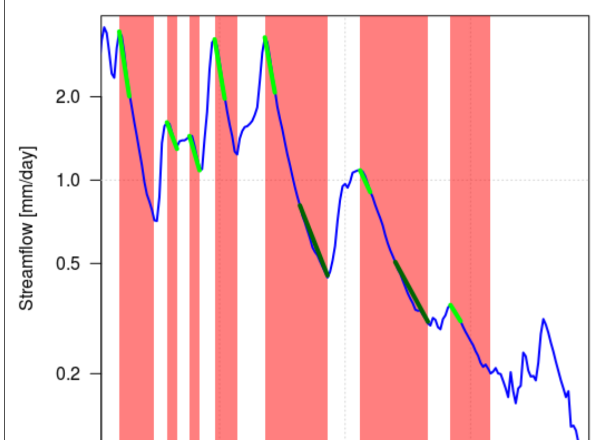


$$BFmag = \frac{BFmax - BFmin}{BFmax}$$

Seasonal P-Q approach



Streamflow recessions



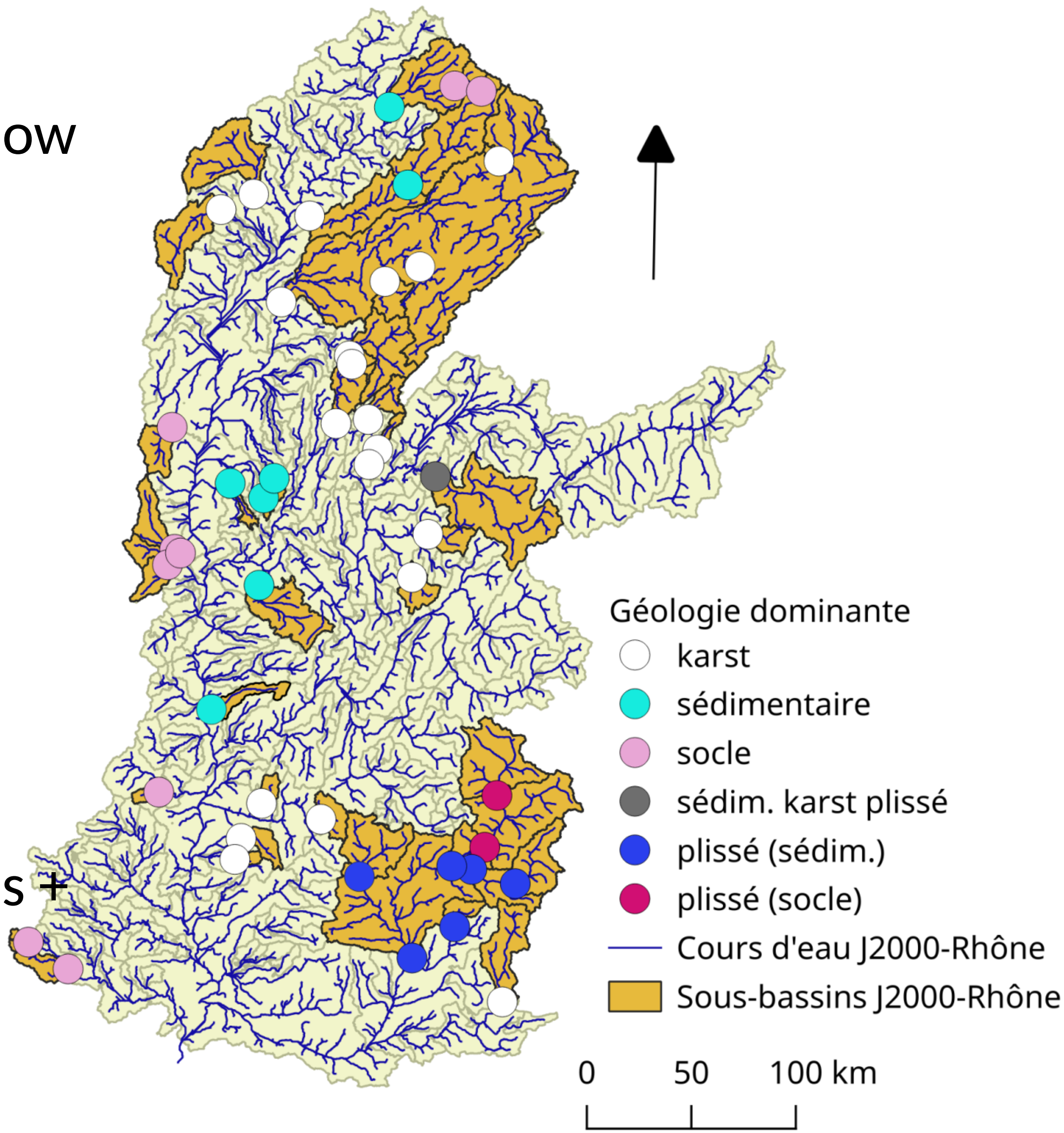
Early recessions (0-5 days) : tau1

Late recessions (15-30 days) : tau2

$$Q(t) \quad = Q_0 e^{-t/\tau}$$

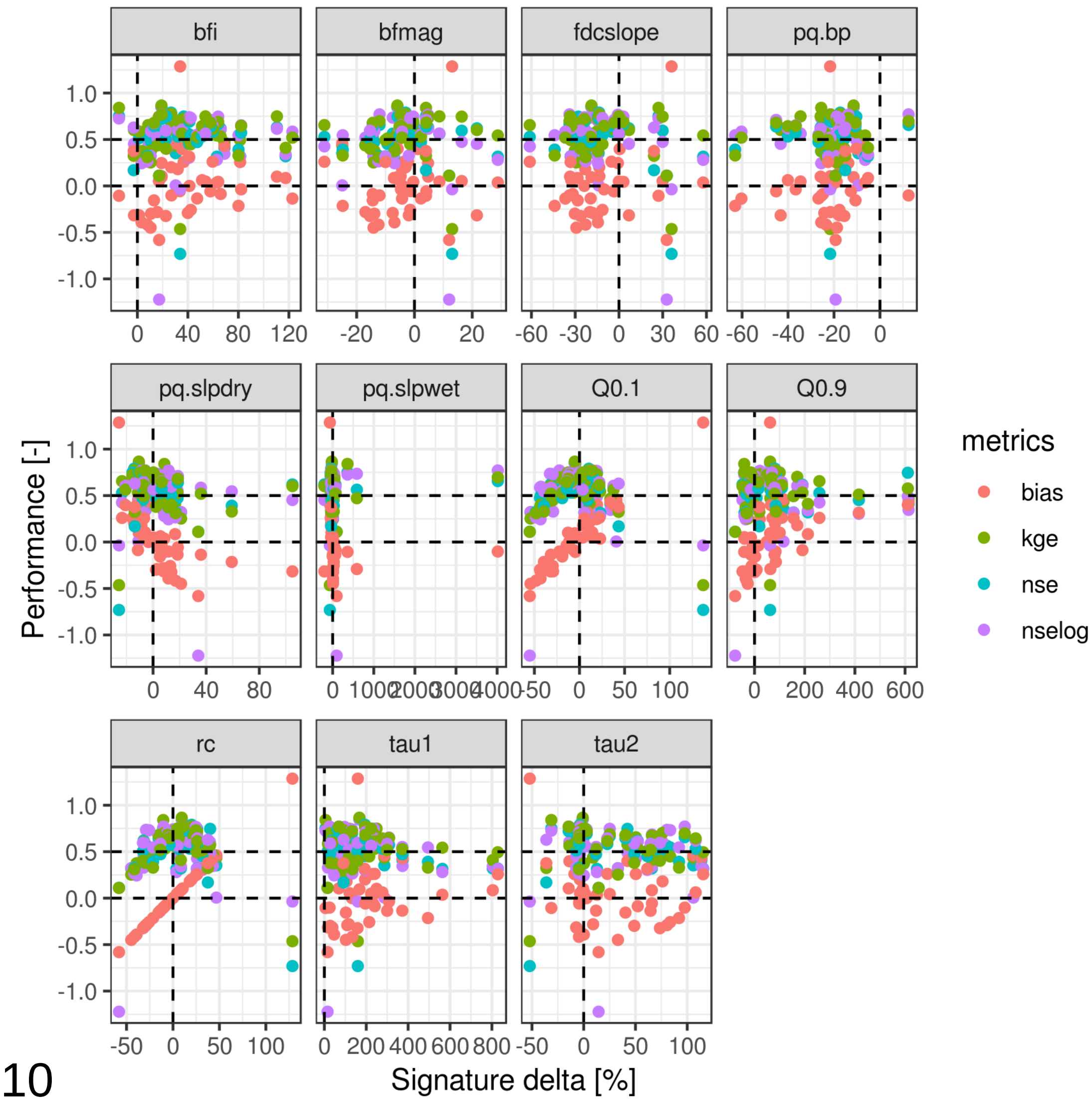
Application to J2000-Rhône

- Selection of 45 stations
  - Reference stations for low flow measurement
  - 34 - 7290 km2
  - Contrasted climate, altitude and geologies
- Performance
  - NSE -1.79 – 0.84
  - KGE -0.46 – 0.87
  - Bias -58 % - +128 %
- Calculation of 11 signatures + groundwater recharge



Hydrological signatures vs performance

11 signatures



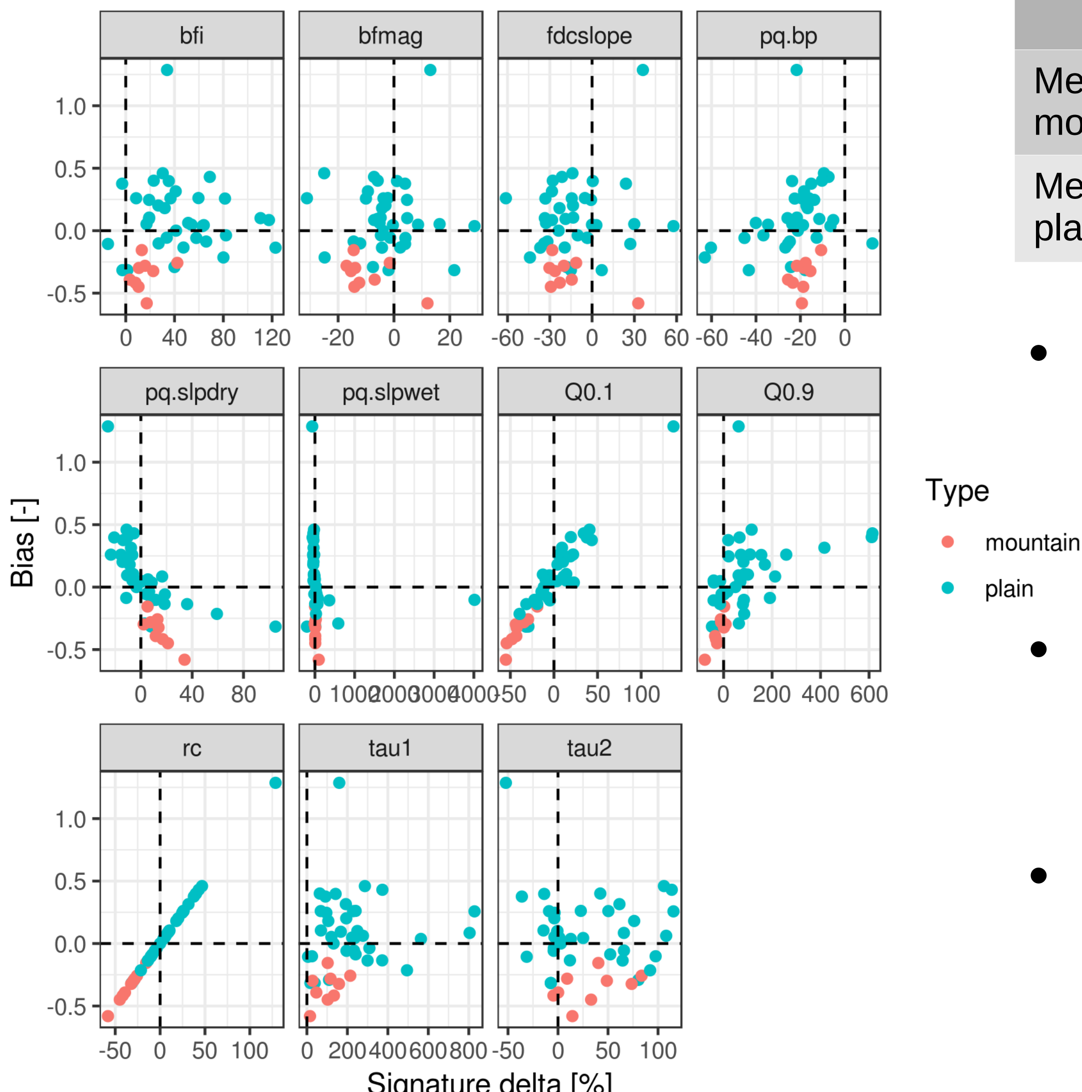
- Quantification of signature difference

$$\Delta_{sig} = \frac{Sim - Obs}{Obs}$$

- No correlation between performance and signature deltas
- Except Bias vs Runoff coefficient (expected), Q0.1 and pq.slpdry

Hydrological signatures vs performance

Mountain catchments



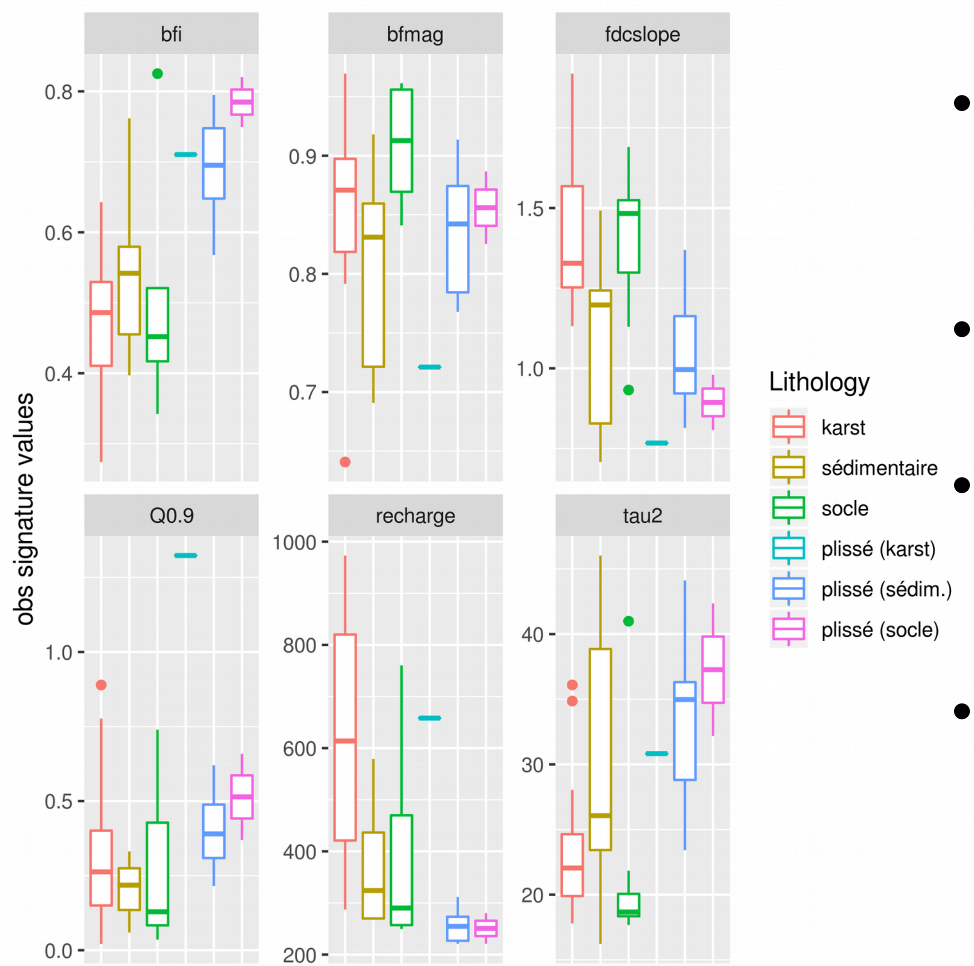
Bias vs signature difference for mountain catchments

	nse	nselog	kge	bias
Mean mountain	0,44	0,30	0,37	-0,35
Mean plain	0,52	0,55	0,58	0,11

- Mountain catchment present overall lower performance than plain catchments (systematic underestimation bias)
- Better reproduction of many signatures (bfi, bfmag, pq.bp, pq.slopes, Q0.9, tau1)…
- There is a know precipitation underestimation bias in the mountains with SAFRAN…

Focus on groundwater processes

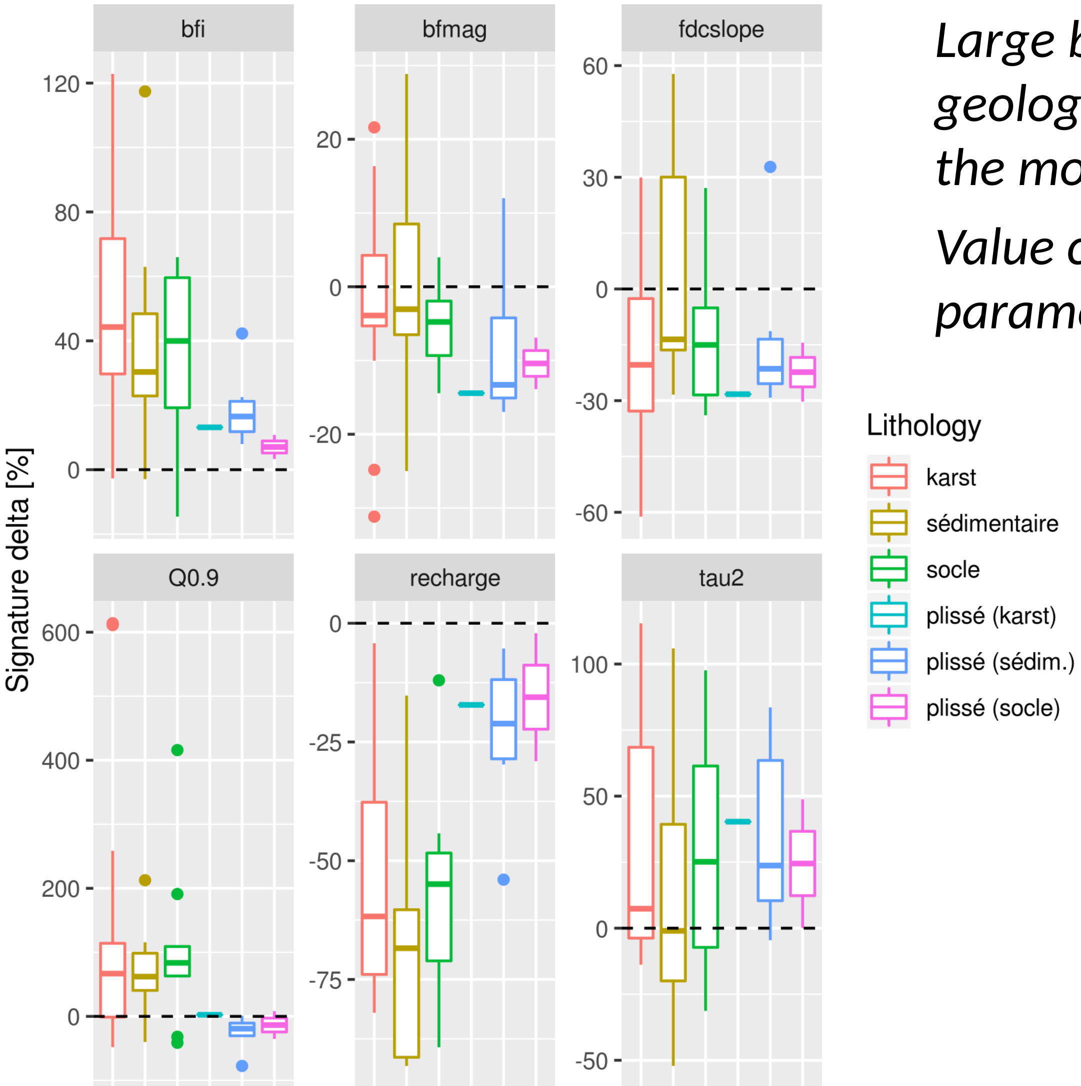
Selection of 5 groundwater-oriented signatures (Horner et al., in prep) + groundwater recharge



Observed signature values according to dominant geology in the catchment

- Analysis of observed signature values
- Confirms significant differences between karstic / non karstic sedimentary geologies
- Also clear differences between mountain / plain catchments
- High variability of sedimentary geologies → should probably be split further
- Sedimentary and basement rock mountain catchments have similar signature values → topography wins over geology

Sim / obs signatures



Large boxplots = large variability => geology classes are too heterogeneous in the model

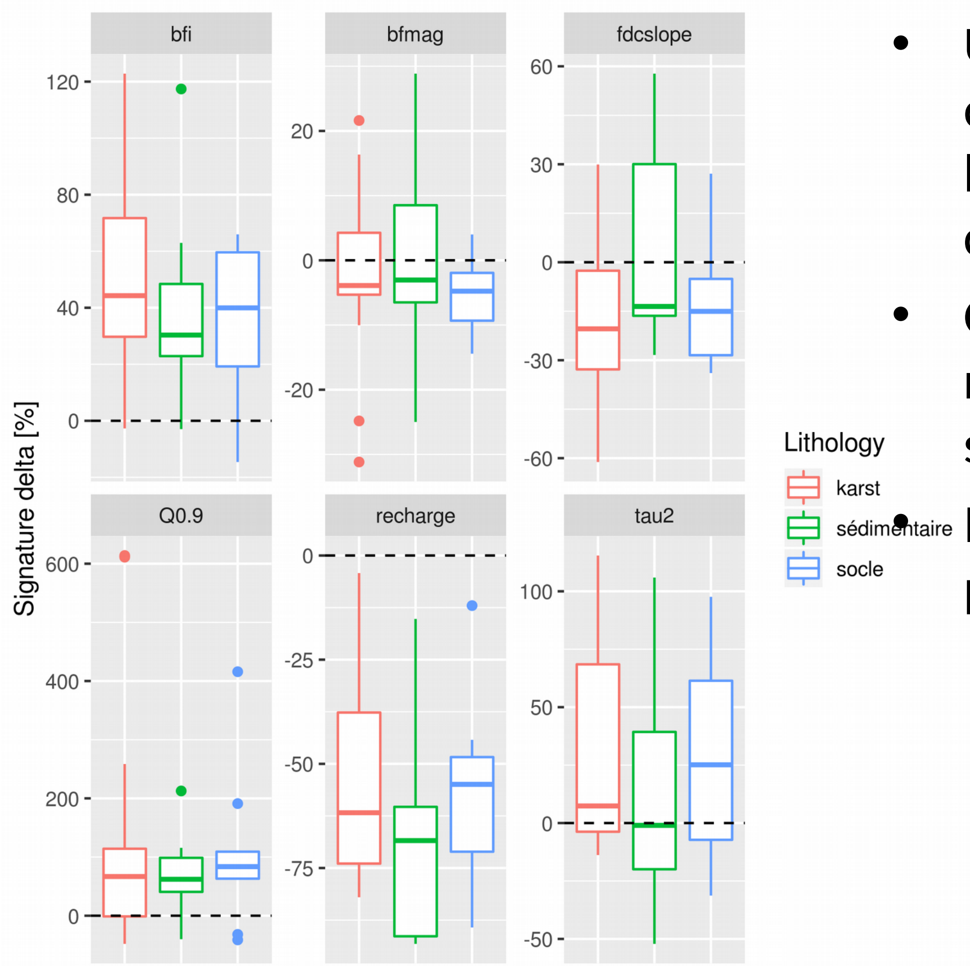
Value close to 0 => more appropriate parameter values

- Confirms that classification and parameterisation are more appropriate for mountain catchments
- Classifications should be reworked for plain catchments

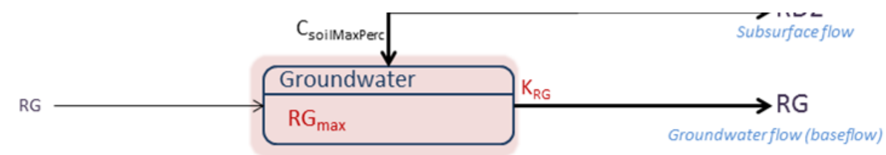
Obs / Sim signature differences according to dominant geology in the catchment

Sim /obs differences interpretation

Obs / Sim signature differences according to dominant geologies for plain catchments



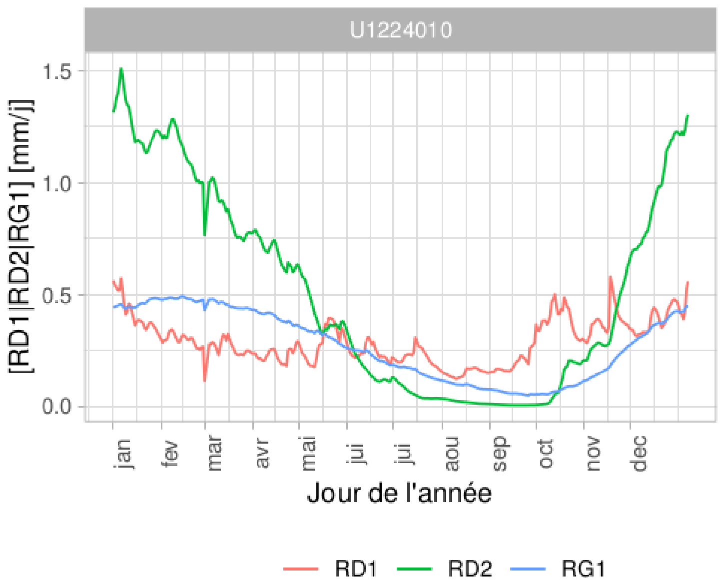
- Too much or not enough baseflow? bfi and recharge : contradictory indicators?
- Underestimated bfmag, fdcslope, and overestimated Q0.9 : too high flow during low flow periods = too high groundwater contribution but maybe not only
- Overestimated tau2 (karst, basement rock) : groundwater contribution too steady
- Interpretation in terms of model parameters : 2 possible factors
  - K_{RG} recession time too long
  - Size RG_{max} too small → RG component always saturated : steady baseflow and no storage effect



Sim /obs interpretation : examples

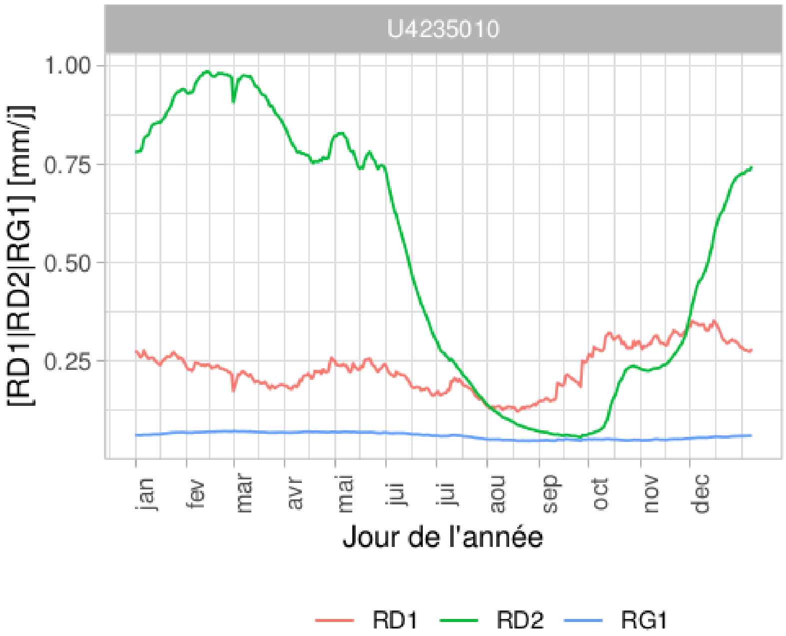
U1224010 : Tille à Arceau [karst]

RG_{max} = 20 mm ; K_{RG} = 20 days



U4235010 : Renon à Neuville-les-Dames [sedim]

RG_{max} = 10 mm ; K_{RG} = 100 days



Simulated flow components : RD1 = surface runoff ; RD2 = interflow ; RG1 = groundwater

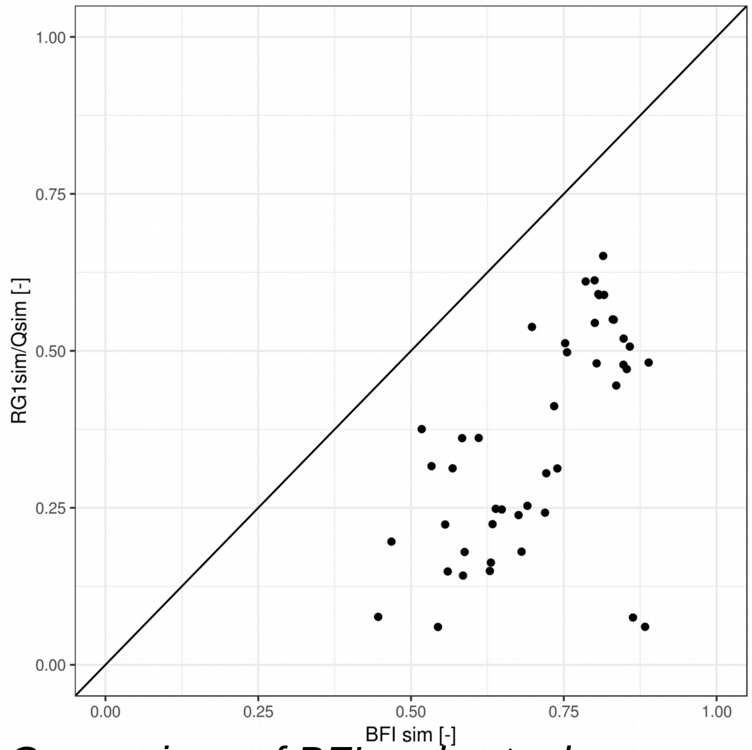
- Low RG_{max} : saturated reservoir → main contribution of RD2 without storage effect
- High K_{RG} : « flat » RG1 component

Conclusions

- Hydrological signatures = interesting insights into model behaviour that as a complement to performance metrics
- Mountain catchments:
  - Low performance / high bias
  - Otherwise good signature values
  - Confirms known bias on SAFRAN forcings
  - Raises the issue of potential compensation of forcings bias during calibration process
- Diagnostic on J2000-Rhône model groundwater component: identification of geology classification + parameter value issues

Conclusions

- Building of a signature set : need to be careful about the information content and redundancy of signatures
  - Correlation Runoff Coefficient / Bias
  - Contradictory BFI / recharge indicators
  - BFI is much larger than actual groundwater contribution
  - It is not representative of groundwater processes only



Comparison of BFI and actual groundwater contribution to total runoff in the model

Perspectives

- Ongoing work :
  - Formalize the links between signature values and parameters (Horner et al., in prep)
  - See if the recommendations for geology classification / parameter improvement actually work !
- Perspectives :
  - Include additional signatures : snow (Horner et al., 2020) and soil moisture (Branger & McMillan, 2020)
  - Extend the diagnostic to the other components of the model (soil, vegetation)
  - Generalize to all control stations of the catchment

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