Comparative study of regionalization methods for simulating low flows from a small number of model parameters

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1. Objectives

- To simulate daily, monthly and annual reference low flows at gauged and ungauged catchments.
- To determine a good efficiency criteria to evaluate and compare model results, good predictions being expected about low flows and references low flows but also annual means and seasonality.
- To compare two methods of regionalization to estimate model parameters.

2. Dataset

- Daily meteorological data (liquid and solid precipitations, temperature and evapotranspiration) come from the SAFRAN reanalysis of Météo–France and daily streamflow data from the French database HYDRO
- Set of 828 catchment throughout France
  - Data available at minimum for 30 years between 1967 and 2008,
  - Surface smaller than 8,000 km²,
  - Natural or with small human influences,
  - Various hydro-meteorological regimes.

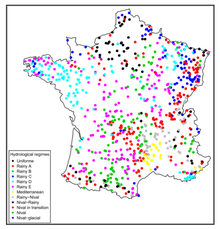


Fig. 1: Spatial distribution and hydrological regimes of the set

Characteristics	Minimum	Quantile 25	Quantile 50	Quantile 75	Maximum
Surface (km²)	2	90	202	478	7920
Runoff (mm/year)	47	265	399	627	2351
Precipitation (mm/year)	630	861	995	1194	2120
Evapotranspiration (mm/year)	220	623	660	702	883

- Low flow frequency indices:
  - Daily indices:
    - MAMd: Mean Annual d-day Minimum flow at the recurrence intervals of T years,
    - DCx: Discharge equaled or exceeded x% of the time, comes from the Flow Duration Curve (FDC)
  - Monthly indices:
    - Qmna: Annual Mean Monthly Flow at the recurrence intervals of T years
  - Annual indices:
    - QA: Mean Annual Runoff

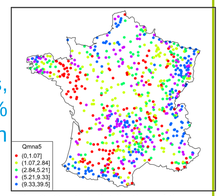


Fig. 2: Spatial distribution of the Qmna5 (mm/month)

3. Efficiency criteria

Methodology

Model

GR4J: a conceptual daily lumped rainfall-runoff model with 4 parameters

Split-sample test

Cross-validation on two sub periods.

	01/01/1967-31/12/1987	01/01/1988-31/12/2008
	Validation 1 Optimization 2	Optimization 1 Validation 2

P1	Rainfall (mm/an)	Evapotranspiration (mm/an)	Flow (mm/an)
Minimum	624	213	26
Mean	1,057	643	464
Maximum	2,109	857	2,380

P2	Rainfall (mm/an)	Evapotranspiration (mm/an)	Flow (mm/an)
Minimum	631	228	41
Mean	1,069	677	454
Maximum	2,128	908	2,303

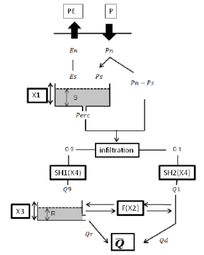


Fig. 3: Structure of the rainfall-runoff model GR4J

Criteria

- Simple criteria: comparison between KGE and NSE calculated with different transformations of the flow (Q, sqrt(Q), log(Q), inv(Q) or Qsorted)

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - \mu_{obs})^2} \qquad KGE = 1 - ED$$

$$\text{avec : } ED = \sqrt{(r-1)^2 + (\alpha-1)^2 + (\beta-1)^2} \qquad \alpha = \frac{\sigma_{sim}^2}{\sigma_{obs}^2} \qquad \beta = \frac{\mu_{sim}}{\mu_{obs}} \qquad r = \frac{1}{n}\sum \frac{(Q_i^{obs} - \mu_{obs})(Q_i^{sim} - \mu_{sim})}{\sigma_{obs}\sigma_{sim}}$$

- Joint criteria: Comparison of combinations of the best simple criteria

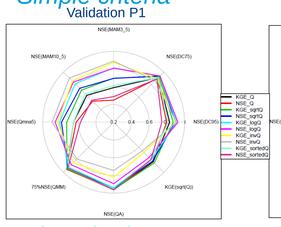
Validation

- On low flows: Qmna, MAM10 and MAM3 for T=5 years
- On seasonality and mean annual: QA and QMM (mean monthly flow)

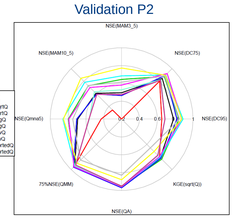
Results

Simple criteria

Validation P1



Validation P2



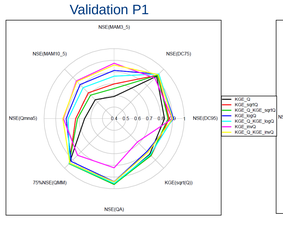
Validation criteria

The simulated flows optimized via a simple criteria are evaluated and compared with the previous indicators.

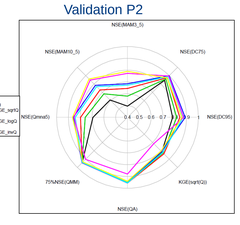
- KGE is more robust than NSE
- KGE and NSE with 1/Q and log(Q) allow a better simulation of low flows but damage a little the seasonality and the mean annual
- The opposite for KGE and NSE on the other transformations of the flows is observed

Joint criteria

Validation P1



Validation P2



Validation criteria

The simulated flows optimized via a simple criteria are evaluated and compared with the previous indicators.

- The joint criteria with sqrt(Q) allows few improvement of the low flow simulations.
- The one with log(Q) allows a better simulation of low flows, and also the mean annual flow and the seasonality.
- The one with inv(Q) is the best one to simulate low flows and also the mean annual flow and the seasonality.

4. Methods of regionalization

Methodology:

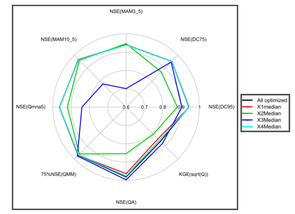
- Regionalization technique:
  - Leave One Out cross-validation
  - Inverse Distance Weighting (IDW) with the squared distance and 5 neighbors
- Regionalization methods:
  - Rough Regionalization: all parameters at once
  - Gradual Regionalization: one parameter is regionalized, the others one optimized, then a second one is regionalized and the remaining ones optimized, and so on until every parameter is regionalized.

Gradual regionalization: choice of the order to regionalize the parameters

4 tests are simulated with one parameter median and the other three optimized with the criteria defined in the third paragraph: 50%*KGE(Q)+50%*KGE(inv(Q)).
Those 4 results are compared with same indicators as before.

- X4 median and the other 3 optimized: low flows, mean annual and seasonality are almost as well simulated as when the 4 parameters are optimized.
- X1 median: the same results are observed.
- X3 median: it can be observed that especially the low flow indicators are not as good simulated
- X2 median: the mean annual and the seasonality are not as good simulated.

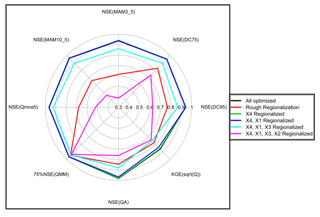
To conclude, X4 will be the first parameter to be regionalized, than X1, than X3 and finally X2.



Results:

All the tests are evaluated with the same criteria as paragraph 3.

- X4 regionalized and the other 3 optimized, and also X4 then X1 regionalized ant the other 2 optimized: all indicators are almost as well simulated as when the 4 parameters are optimized.
- 3 parameters, X4, then X1, then X3 regionalized: the results are a little less good than with all parameters regionalized or all optimized
- All parameters gradually regionalized: low flows are especially not good simulated.
- The parameters regionalized with the rough method: it does not allow to simulate low flows as good as when they are all optimized.
- Finally, with this technique of regionalization (IDW), the rough regionalization method allows to simulate better low flows than the gradual regionalized method when all 4 parameters are regionalized.



5. Discussions

Efficiency criteria

- The best efficiency criteria tested to simulate low flows is the joint criteria: 50% KGE(Q) and 50% KGE(inv(Q))
- This criteria will be tested with an other rainfall-runoff model which structure is developed to simulate low flows.

Regionalization

- The rough method seems to be better than the gradual one with the IDW technique
- Those methods will be tested with other techniques using physical variables.

References

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