Catchment memory of climate anomalies

Alban de Lavenne, Vazken Andréassian, Louise Crochemore

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OZCAR – TERENO International Conference

Alban de Lavenne[1] , Vazken Andréassian[1] , Louise Crochemore[2]

2021-10-05

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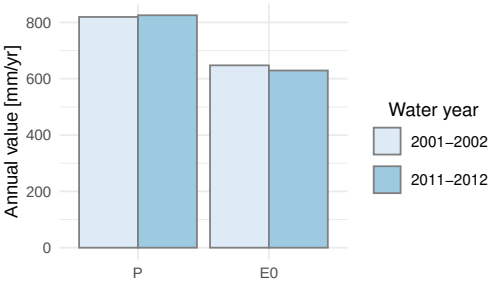
A simple annual water balance issue

A textbook case: “Le Petit Thérain à Saint-Omer-en-Chaussée” (212 km^2)

How very similar years...



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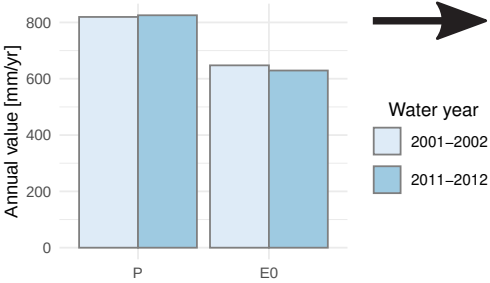
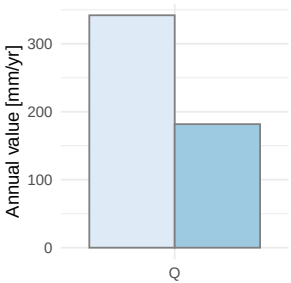
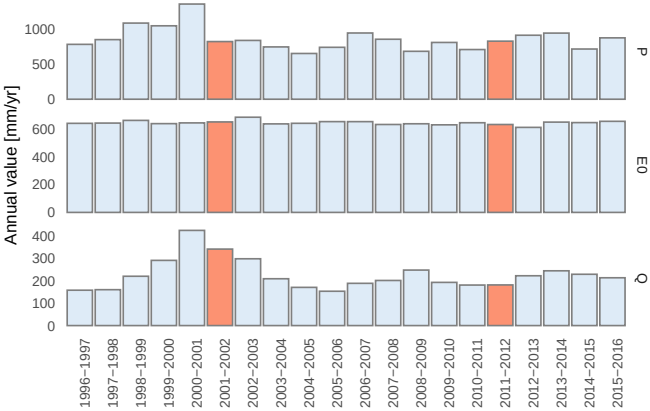


...could lead to very different runoff productions?

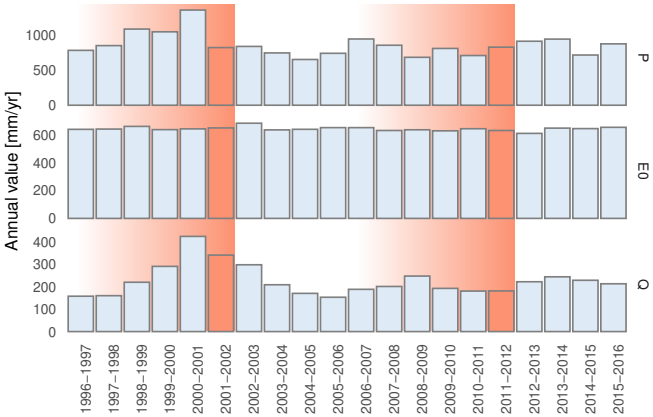


Catchment long-term water storage dynamic



- The behaviour of the catchment depends strongly on the past years

Catchment long-term water storage dynamic



How long do catchments remember climate anomalies?

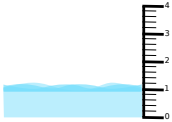
- The behaviour of the catchment depends strongly on the past years
- We will focus on **long-term (multi-year)** water storage dynamics

A usual elasticity analysis

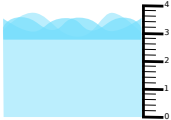
Elasticity *measures the percentage change of one variable in response to a change in another.*

Anomalies defined by: $\frac{X_i - \overline{X}}{\overline{X}} = \frac{\delta X}{\overline{X}}$

A dry year



A wet year



H = P/E$_0$ anomaly

Y = Q/P anomaly

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$$\frac{\delta Y}{\overline{Y}} = \varepsilon_1 \frac{\delta H}{\overline{H}}$$

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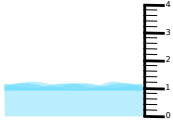
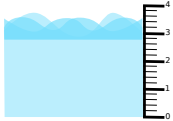


A wet year



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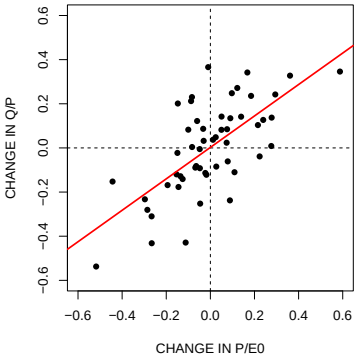
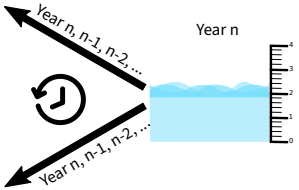


A revisited elasticity analysis to consider catchment memory

A dry year

A wet year



H = P/E$_0$ anomaly

Y = Q/P anomaly

A revisited elasticity analysis to consider catchment memory

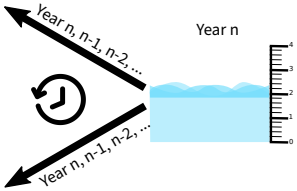
$$\frac{\delta Y_0}{\overline{Y}} = \varepsilon_2 \sum_{i=0}^{n} \left(\omega_i \cdot \frac{\delta H_i}{\overline{H}} \right)$$

A weighted average value

A dry year

A wet year

H = P/E$_0$ anomaly



Y = Q/P anomaly

- A new elasticity index ε_2 that considers catchment memory

A revisited elasticity analysis to consider catchment memory

A weighted average value

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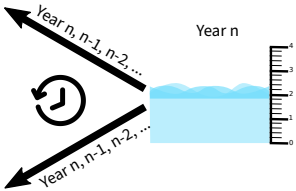
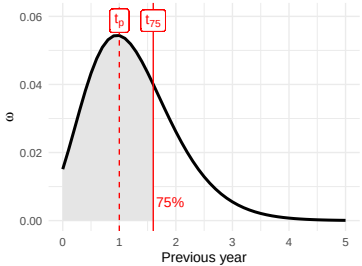


Y = Q/P anomaly

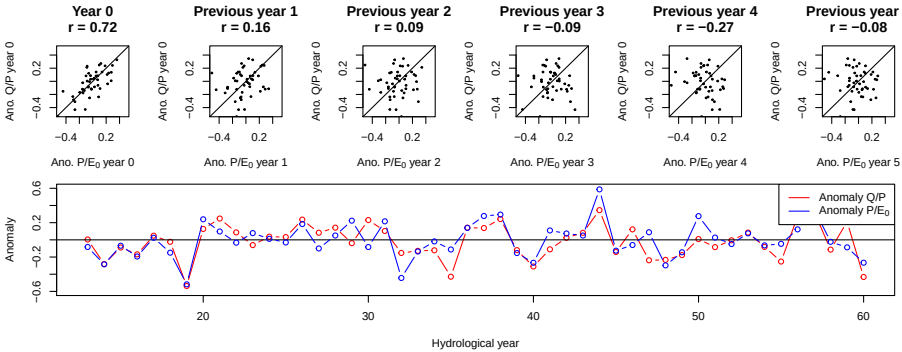
$$\frac{\delta Y_0}{\overline{Y}} = \varepsilon_2 \sum_{i=0}^{n} \left(\omega_i \cdot \frac{\delta H_i}{\overline{H}} \right)$$

With ω following a Gamma distribution:



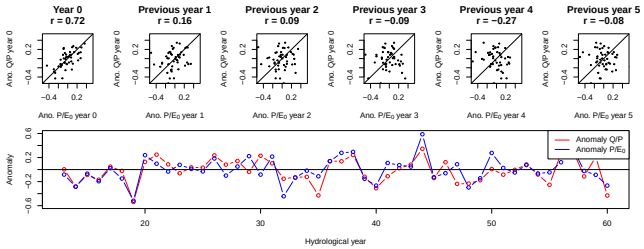
- A new elasticity index ε_2 that considers catchment memory
- The concept of **catchment forgetting curves** following Ebbinghaus (1885)

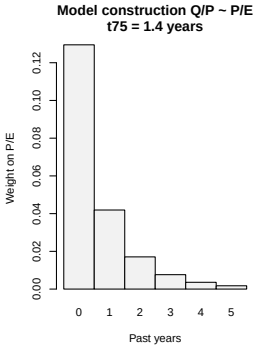
Some examples of catchments



Coët-Organ at Quistinic (45 km^2)

Some examples of catchments





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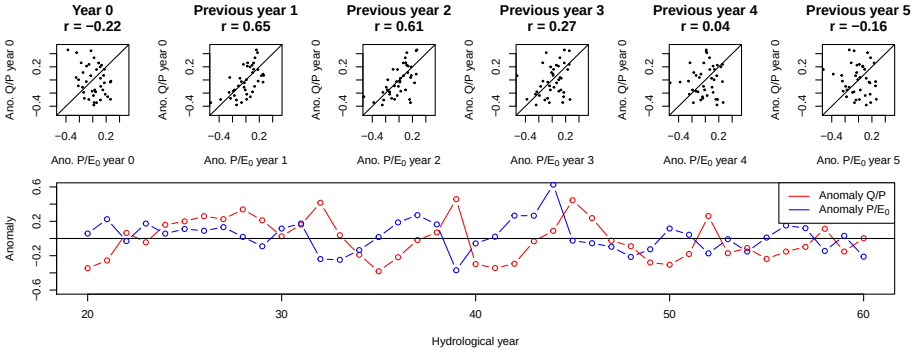
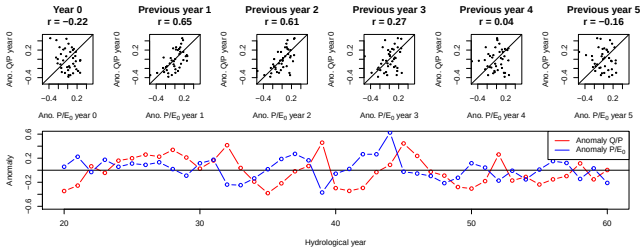
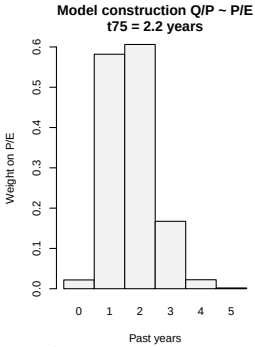


Petit Thérain at Saint-Omer-en-Chaussée (214 km^2)

Some examples of catchments





Petit Thérain at Saint-Omer-en-Chaussée (214 km^2)

In summary, two elasticity analyses

Usual approach:

$$\frac{\delta Y}{\overline{Y}} = \varepsilon_1 \frac{\delta H}{\overline{H}}$$

1 parameter: ε_1

Considering catchment memory:

$$\frac{\delta Y_0}{\overline{Y}} = \varepsilon_2 \sum_{i=0}^{n} \left(\omega_i \cdot \frac{\delta H_i}{\overline{H}} \right)$$

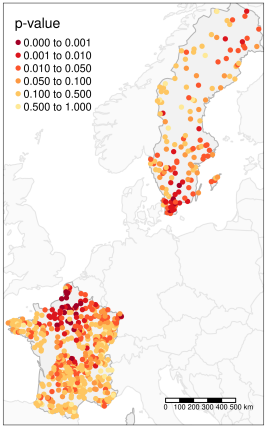
$$\text{with} \sum_{i=0}^{n} \omega_i = 1$$

3 parameters: ε_2 and the Gamma distribution (α and β)

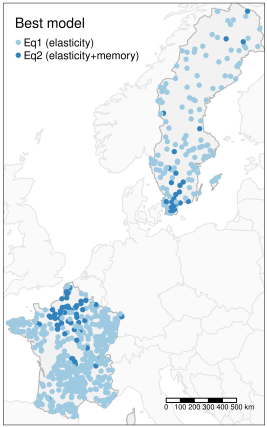
A statistical comparison to detect catchments with significant memory

Database 527 French catchments + 158 Swedish catchments
From 23 to 59 years of discharge observation

Few indices of catchment memory



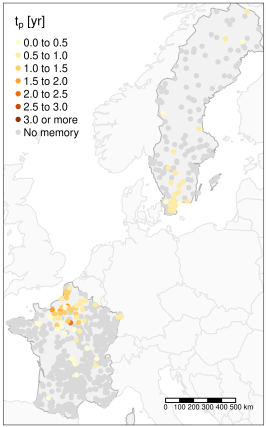
(a) p-value of the t-Test



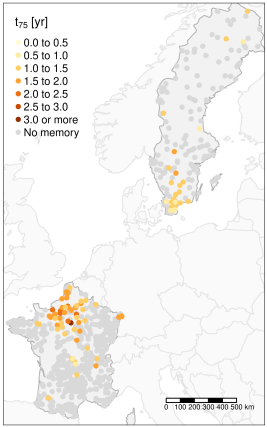
(b) Model selection

- Approximately 80% of the Swedish catchments and 89% of the French catchments showed no significant pluriannual memory

Few indices of catchment memory



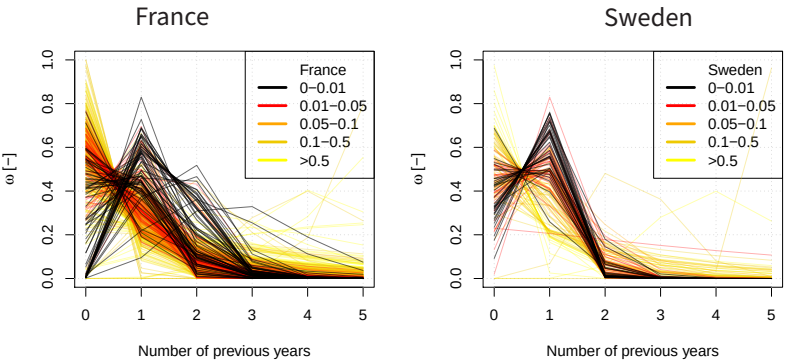
(c) Memory lag t_p



(d) Catchment memory t_{75}

- Approximately 80% of the Swedish catchments and 89% of the French catchments showed no significant pluriannual memory
- Memory generally longer in France than in Sweden

The catchment forgetting curves (CFCs)



Forgetting curves to take into account a lag in catchment response
Shape of the CFCs highlights different dynamics France vs Sweden

- Often no memory of year 0 in France
- French catchments remember past climate longer

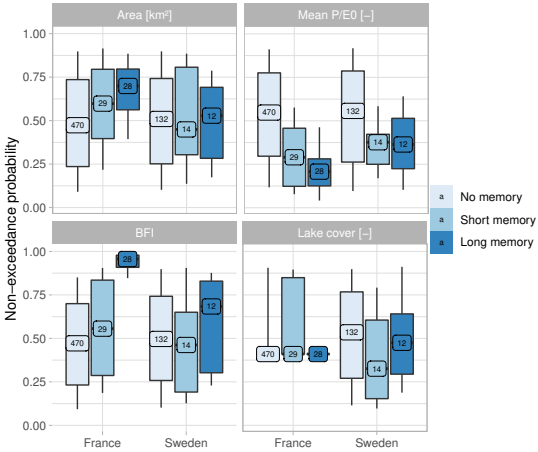
Drivers of catchment memory

Main drivers of catchment memory:

BFI (baseflow index) in France only

Humidity dryer conditions = longer memory in both countries

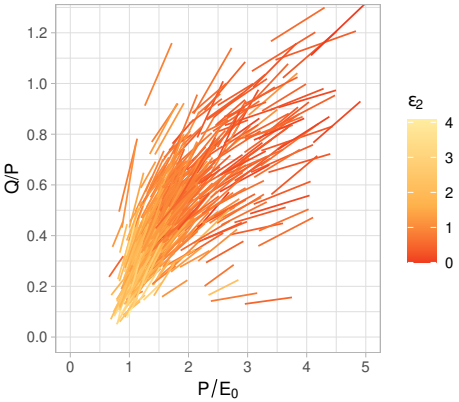
Area and lakes? do not have major influence



Drivers of elasticity

The elasticity depends also on humidity index:

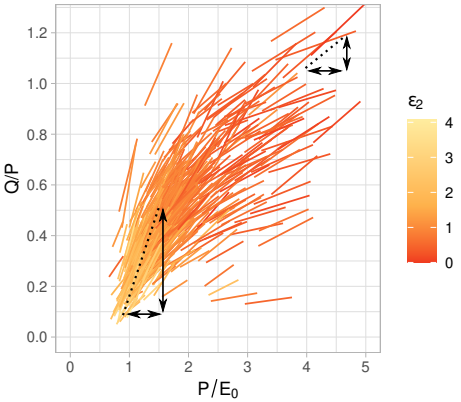
- Low $P/E_0 \Rightarrow$ High ε_2



Drivers of elasticity

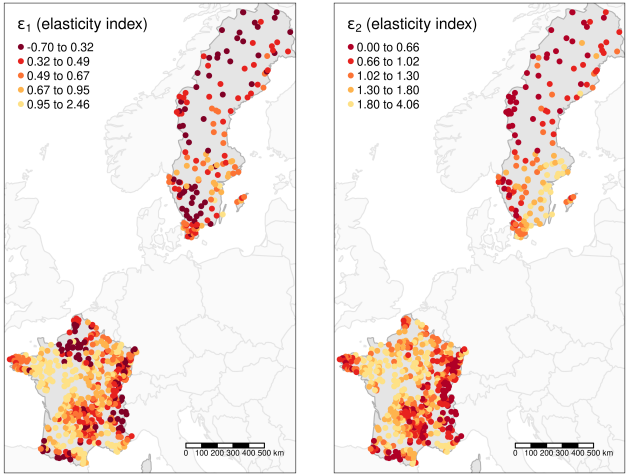
The elasticity depends also on humidity index:

- Low $P/E_0 \Rightarrow$ High ε_2
- Q/P is more sensitive when P/E_0 is low



New maps of the elasticity index

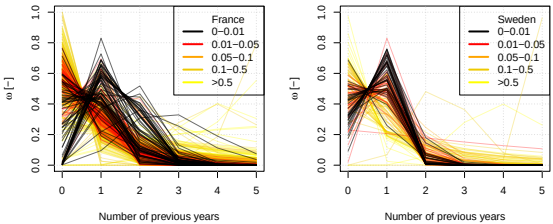
A more reliable map of the elastic relation $Q/P \sim P/E_0$



(a) ε_1: Elasticity index of equation 1 (b) ε_2: Elasticity index of equation 2

Conclusion

- The concept of **Catchment Forgetting Curves** (CFCs)



- A correction of **elasticity** analysis to account for catchment memory
- **Humidity index and BFI**: main drivers of memory and elasticity
- For more details, see the ongoing discussion in HESS:

de Lavenne A, Andréassian V, Crochemore L, Lindström G, Arheimer B. (2021) Quantifying pluriannual hydrological memory with Catchment Forgetting Curves. *HESSD*. DOI: 10.5194/hess-2021-331

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