



Catchment memory of climate anomalies

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Catchment memory of climate anomalies

OZCAR – TERENO International Conference

Alban de Lavenne¹, Vazken Andréassian¹, Louise Crochemore²

2021-10-05

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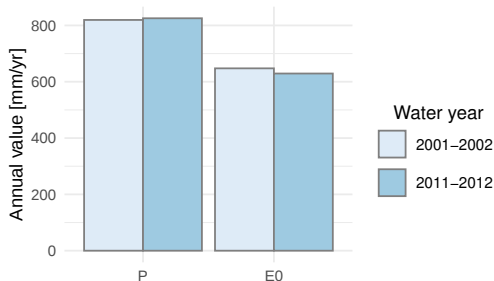
² Université Grenoble Alpes, CNRS, IRD, Grenoble INP, IGE, Grenoble, France

A simple annual water balance issue

A textbook case: “Le Petit Thérain à Saint-Omer-en-Chaussée” (212 km²)



How
very similar years...



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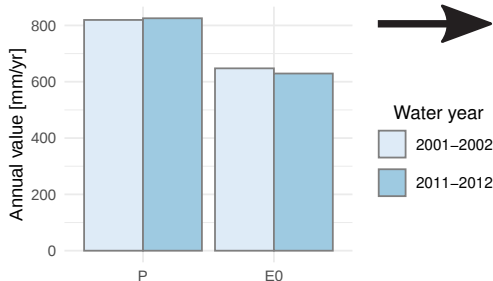
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A simple annual water balance issue

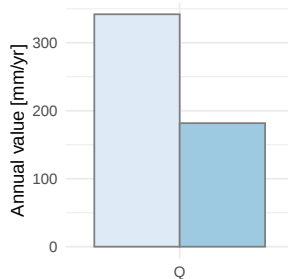
A textbook case: “Le Petit Thérain à Saint-Omer-en-Chaussée” (212 km²)



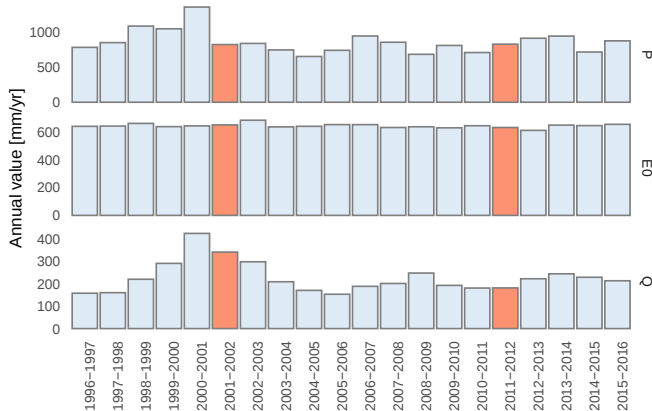
How
very similar years...



...could lead to
very different runoff productions?



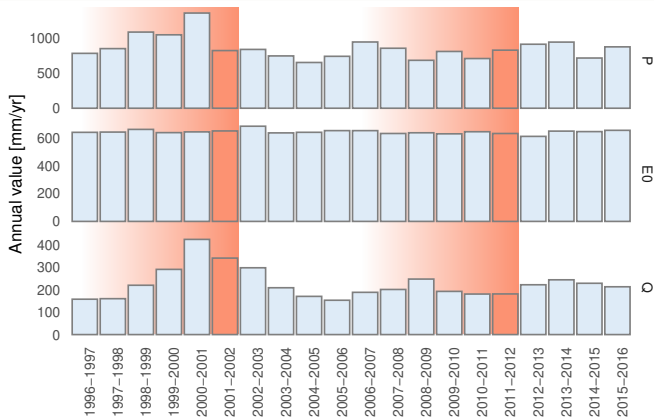
Catchment long-term water storage dynamic



- 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: $\frac{X_i - \bar{X}}{\bar{X}} = \frac{\delta X}{\bar{X}}$

A dry year



A wet year



$H = P/E_0$
anomaly

$Y = Q/P$
anomaly

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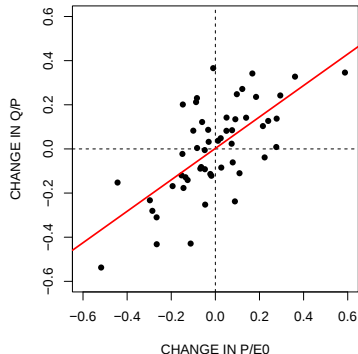
A wet year



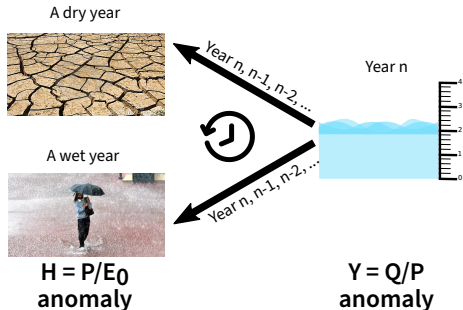
$H = P/E_0$
anomaly

$Y = Q/P$
anomaly

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



A revisited elasticity analysis to consider catchment memory



A revisited elasticity analysis to consider catchment memory

**A weighted
average
value**

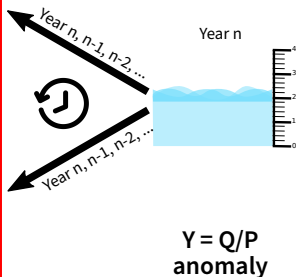
A dry year



A wet year



$H = P/E_0$
anomaly



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

- A new elasticity index ε_2 that considers catchment memory



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A revisited elasticity analysis to consider catchment memory

A weighted
average
value

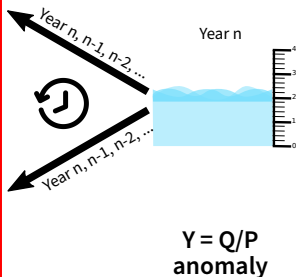
A dry year



A wet year



$H = P/E_0$
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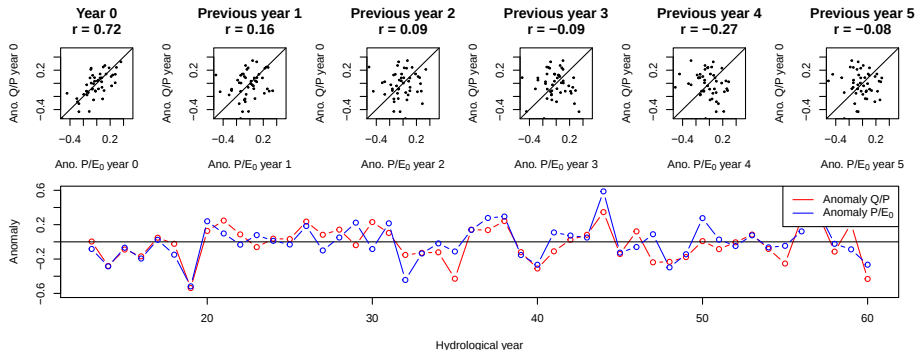
$$\frac{\delta Y_0}{\bar{Y}} = \varepsilon_2 \sum_{i=0}^n \left(\omega_i \cdot \frac{\delta H_i}{\bar{H}} \right)$$

With ω following a Gamma distribution:



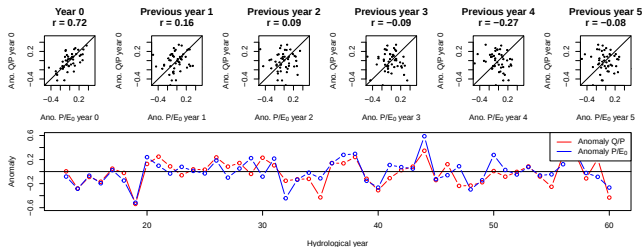
- A new elasticity index ε_2 that considers catchment memory
- The concept of **catchment forgetting curves** following Ebbinghaus (1885)

Some examples of catchments

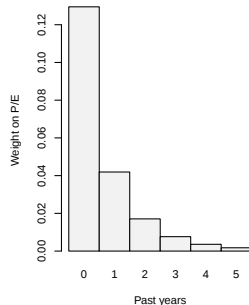


Coët-Organ at Quistinic (45 km²)

Some examples of catchments

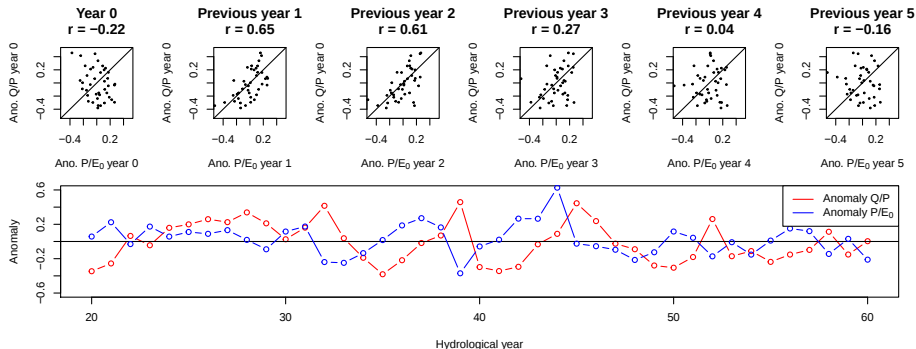


Model construction Q/P ~ P/E
t75 = 1.4 years



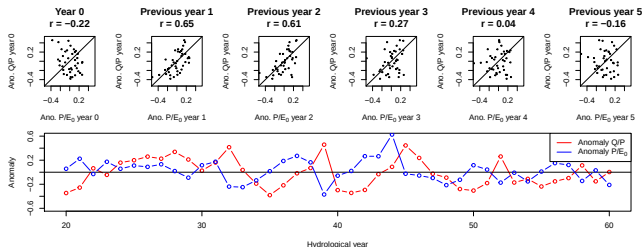
Coët-Organ at Quistinic (45 km²)

Some examples of catchments

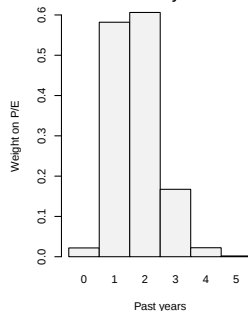


Petit Thérain at Saint-Omer-en-Chaussée (214 km²)

Some examples of catchments



Model construction Q/P ~ P/E
 $t75 = 2.2$ years



Petit Thérain at Saint-Omer-en-Chaussée (214 km²)

In summary, two elasticity analyses

Usual approach:

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

1 parameter: ε_1

Considering catchment memory:

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

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

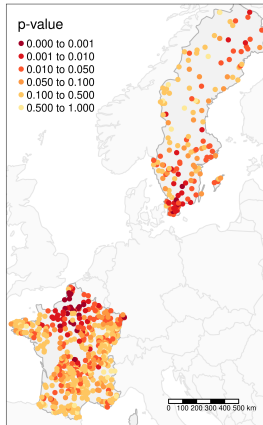
3 parameters: ε_2 and the Gamma distribution (α and β)

A statistical comparison to detect catchments with significant memory

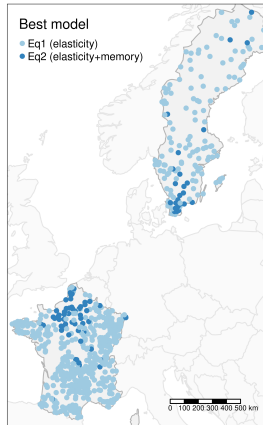
Database 527 French catchments + 158 Swedish catchments
From 23 to 59 years of discharge observation



Few indices of catchment memory



(a) p-value of the t -Test

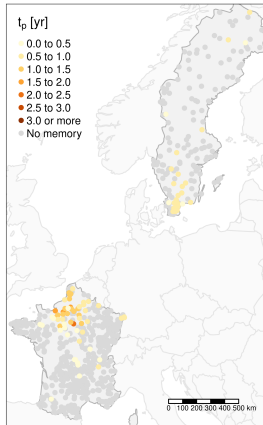


(b) Model selection

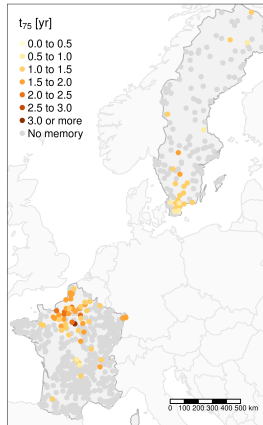
- Approximately 80% of the Swedish catchments and 89% of the French catchments showed no significant pluriannual memory



Few indices of catchment memory



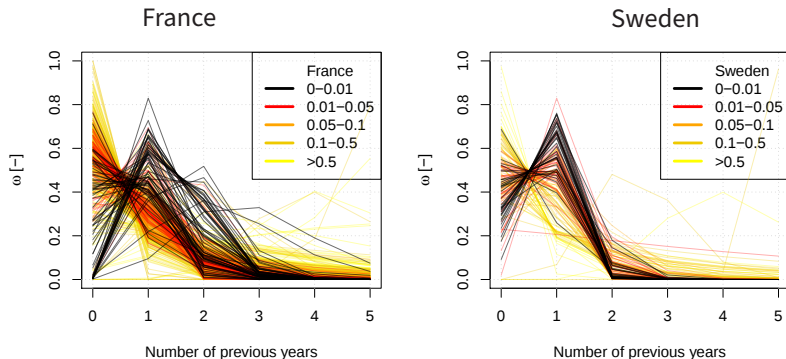
(c) Memory lag t_p



(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



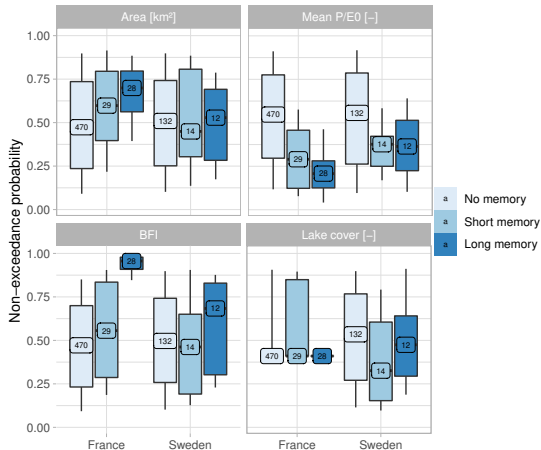
Drivers of catchment memory

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



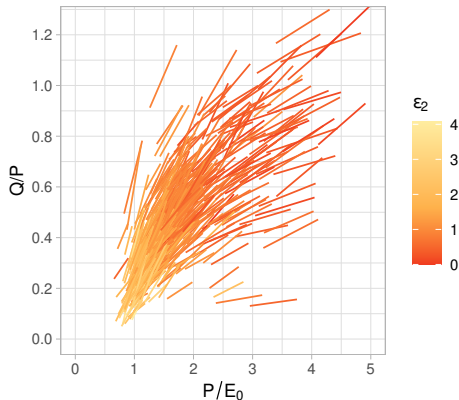
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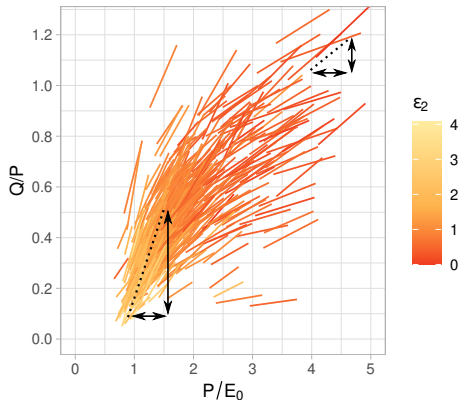
The elasticity depends also
on humidity index:

- Low $P/E_0 \Rightarrow$ High ε_2



The elasticity depends also on humidity index:

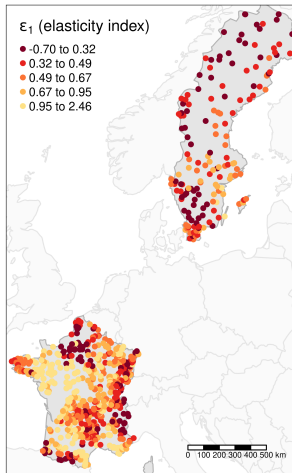
- Low $P/E_0 \Rightarrow$ High ε_2
- Q/P is more sensitive when P/E_0 is low



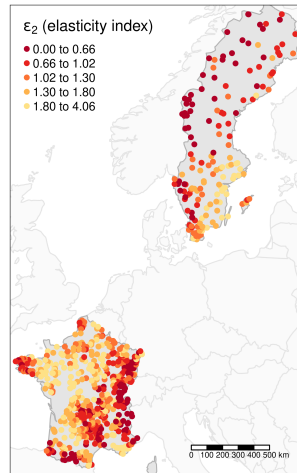
New maps of the elasticity index

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

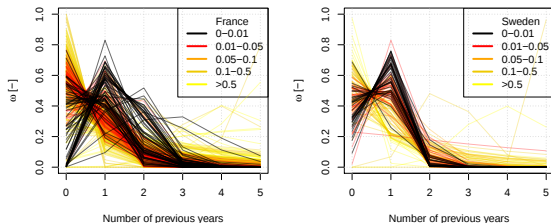


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- The concept of **Catchment Forgetting Curves (CFCs)**



- 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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