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## Catchment memory of climate anomalies

Alban de Lavenne, Vazken Andréassian, Louise Crochemore

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# Catchment memory of climate anomalies

OZCAR – TERENO International Conference

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2021-10-05

<sup>1</sup> Université Paris-Saclay, INRAE, UR HYCAR, Antony, France

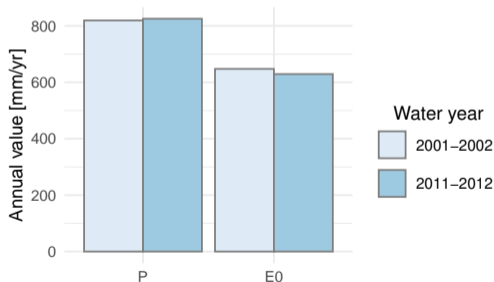
<sup>2</sup> Université Grenoble Alpes, CNRS, IRD, Grenoble INP, IGE, Grenoble, France

# A simple annual water balance issue

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



How  
very similar years...



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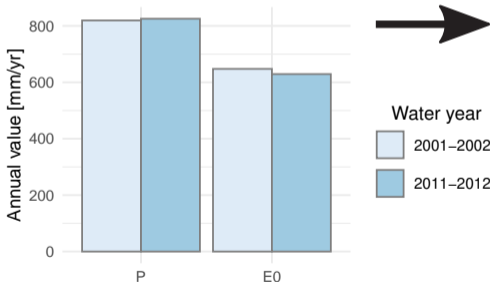
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# A simple annual water balance issue

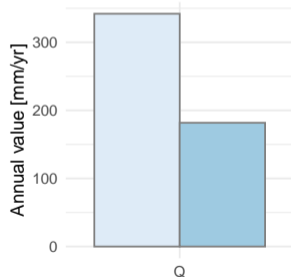
A textbook case: “Le Petit Thérain à Saint-Omer-en-Chaussée” (212 km<sup>2</sup>)



How  
very similar years...



...could lead to  
very different runoff productions?

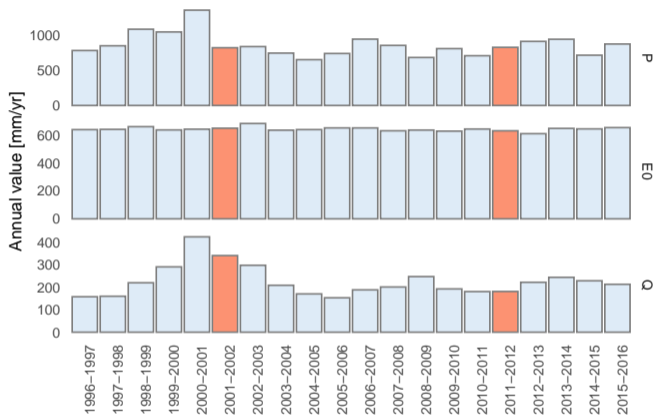


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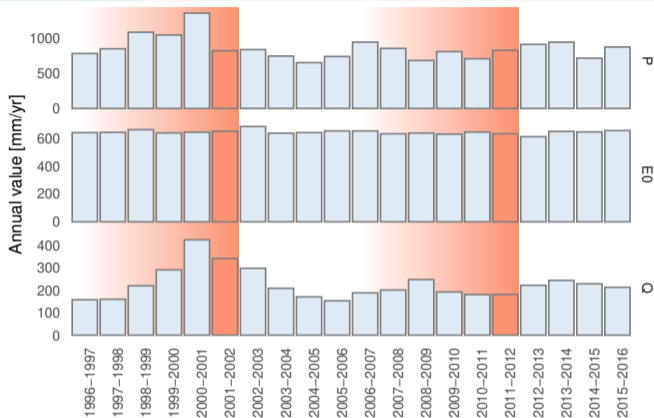
# Catchment long-term water storage dynamic



- 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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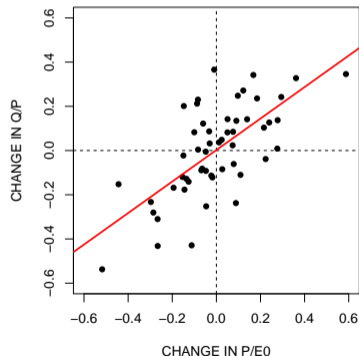
A wet year



$H = P/E_0$   
anomaly

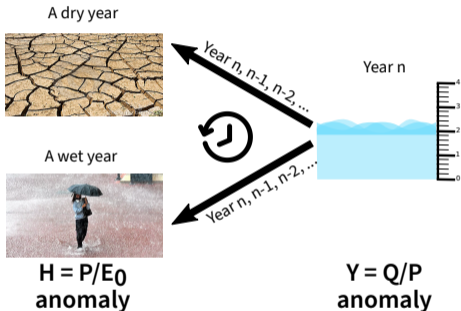
$Y = Q/P$   
anomaly

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

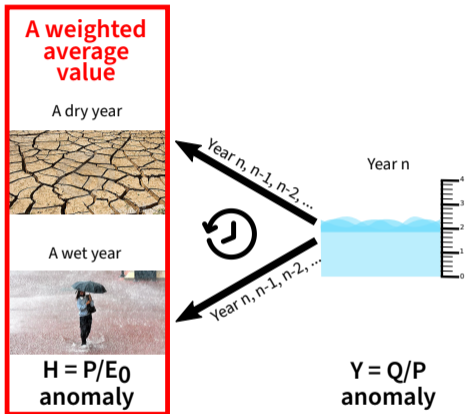




# A revisited elasticity analysis to consider catchment memory



# A revisited elasticity analysis to consider catchment memory



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

- A new elasticity index  $\varepsilon_2$  that considers catchment memory



# A revisited elasticity analysis to consider catchment memory

**A weighted average value**

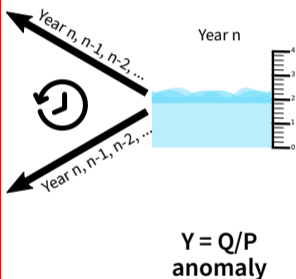
A dry year



A wet year

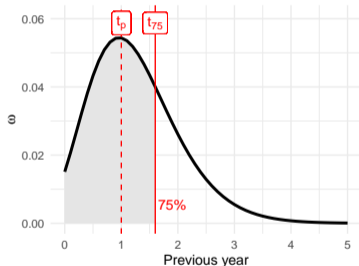


$H = P/E_0$   
anomaly



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

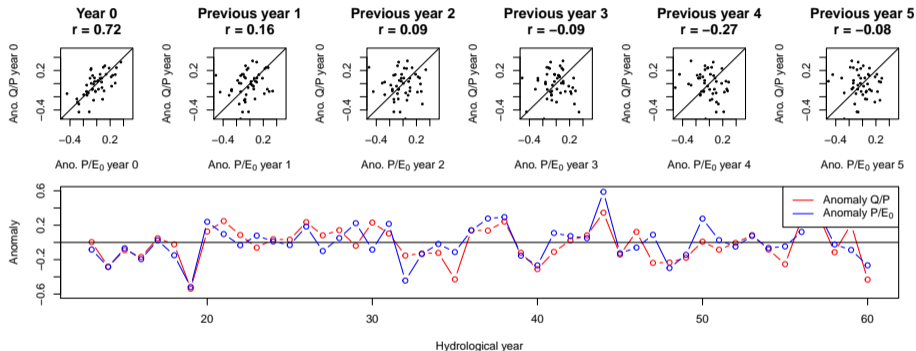
With  $\omega$  following a Gamma distribution:



- A new elasticity index  $\varepsilon_2$  that considers catchment memory
- The concept of **catchment forgetting curves** following Ebbinghaus (1885)



# Some examples of catchments



Coët-Organ at Quistinic (45 km<sup>2</sup>)

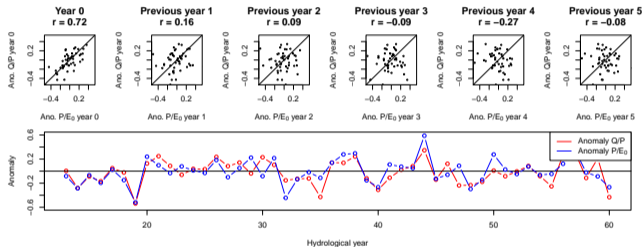


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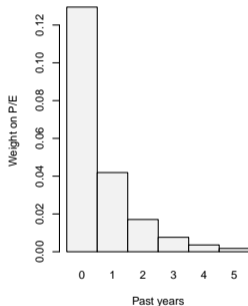
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# Some examples of catchments

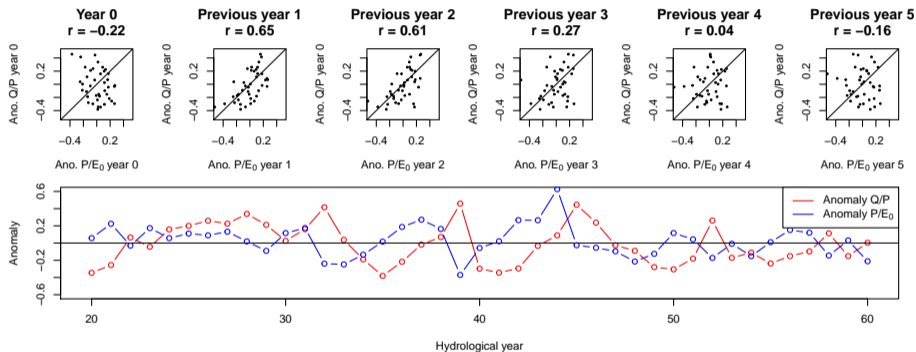


Coët-Organ at Quistinic (45 km<sup>2</sup>)

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



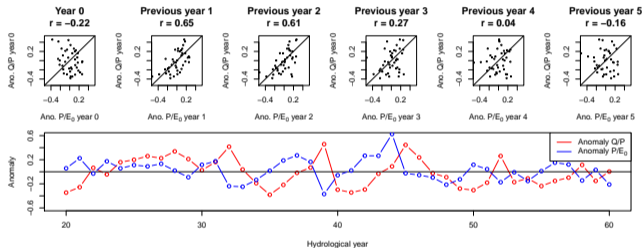
# Some examples of catchments



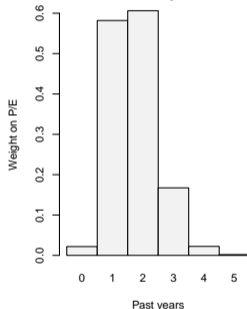
Petit Thérain at Saint-Omer-en-Chaussée (214 km<sup>2</sup>)



# Some examples of catchments



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



Petit Thérain at Saint-Omer-en-Chaussée (214 km<sup>2</sup>)



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## In summary, two elasticity analyses

### Usual approach:

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

1 parameter:  $\varepsilon_1$

### 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:  $\varepsilon_2$  and the Gamma distribution ( $\alpha$  and  $\beta$ )

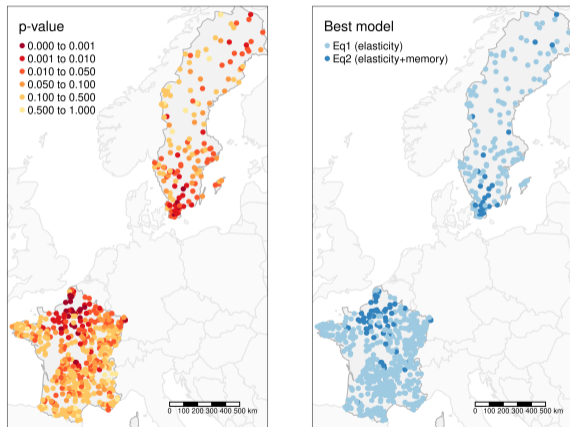
**A statistical comparison** to detect catchments with significant memory

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





# Few indices of catchment memory



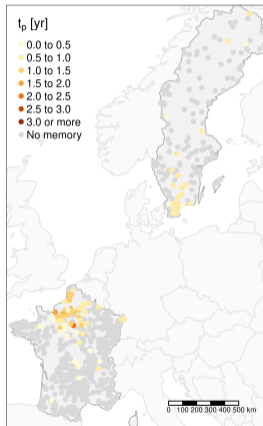
(a) p-value of the *t*-Test

(b) Model selection

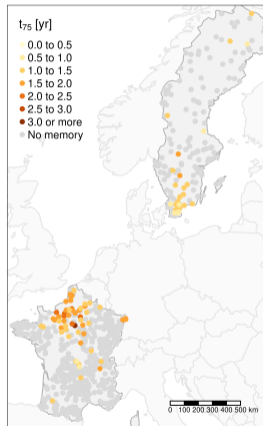
- Approximately 80% of the Swedish catchments and 89% of the French catchments showed no significant pluriannual memory



# Few indices of catchment memory



(c) Memory lag  $t_p$

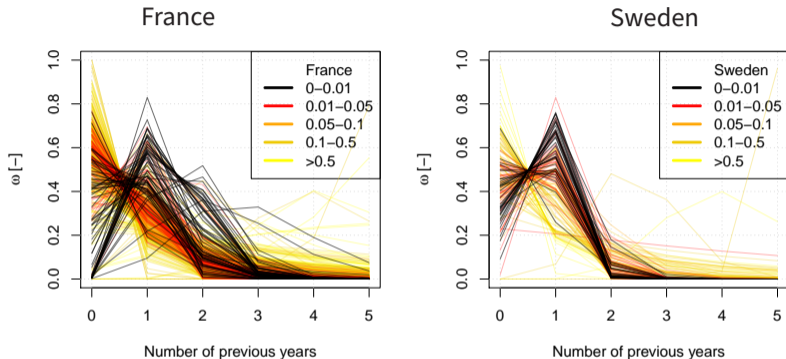


(d) Catchment memory  $t_{75}$

- 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



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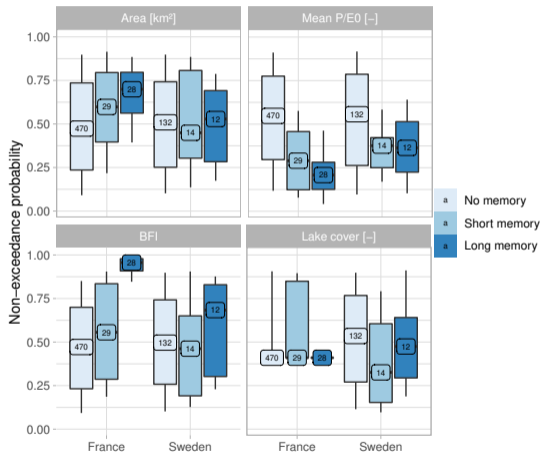
# Drivers of catchment memory

Main drivers of catchment memory:

**BFI** (baseflow index) in France only

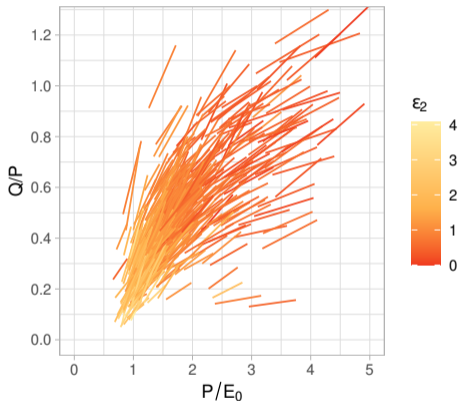
**Humidity** dryer conditions = longer memory in both countries

**Area and lakes?** do not have major influence



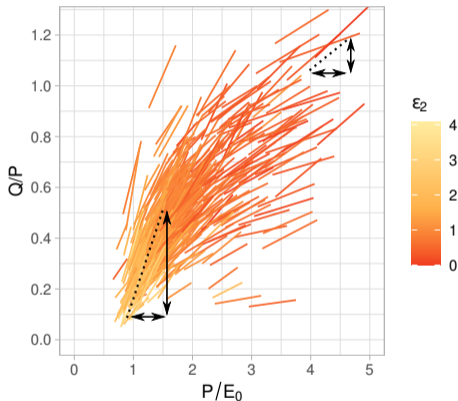
The elasticity depends also on humidity index:

- Low  $P/E_0 \Rightarrow$  High  $\varepsilon_2$



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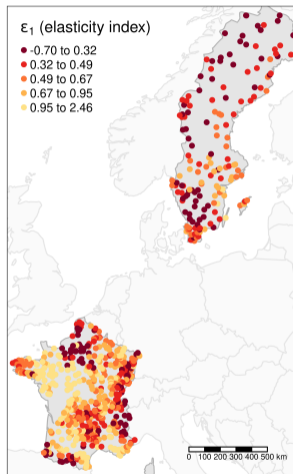
- Low  $P/E_0 \Rightarrow$  High  $\varepsilon_2$
- $Q/P$  is more sensitive when  $P/E_0$  is low



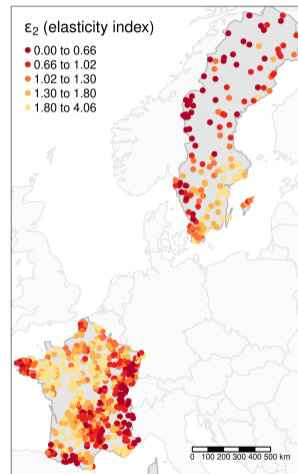
# New maps of the elasticity index

A more reliable map of  
the elastic relation

$$Q/P \sim P/E_0$$



(a)  $\epsilon_1$ : Elasticity index of equation 1



(b)  $\epsilon_2$ : Elasticity index of equation 2

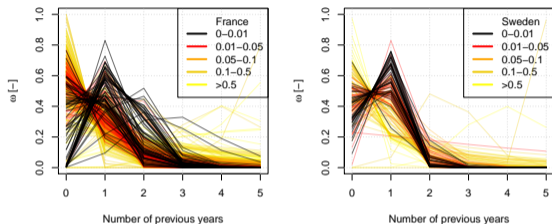


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- The concept of **Catchment Forgetting Curves (CFCs)**



- 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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