



**HAL**  
open science

# **Beyond Local Models: Generalizing Deep Learning for Groundwater Simulation Across Hydrogeological Diversity and Mixed Influences**

Asmae Ez-Zahy, Nicolas Massei, Abderrahim Jardani, Lisa Baulon, Hugo Breuillard, Augustin Thomas, Sivarama Krishna Reddy Chidepudi

## **► To cite this version:**

Asmae Ez-Zahy, Nicolas Massei, Abderrahim Jardani, Lisa Baulon, Hugo Breuillard, et al.. Beyond Local Models: Generalizing Deep Learning for Groundwater Simulation Across Hydrogeological Diversity and Mixed Influences. ELLIS Summer School: AI for Earth and Climate Sciences, Sep 2025, Jena, Germany. <hal-05524198>

**HAL Id: hal-05524198**

**<https://brgm.hal.science/hal-05524198v1>**

Submitted on 23 Feb 2026

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License

Asmae Ez-zahy<sup>1,2\*</sup>, Nicolas Massei<sup>1</sup>, Abderrahim Jardani<sup>1</sup>, Lisa Baulon<sup>2</sup>, Hugo Breuillard<sup>2</sup>, Augustin Thomas<sup>2</sup>, and Sivarama Krishna Reddy Chidepudi<sup>1</sup>

<sup>1</sup> Univ Rouen Normandie, Univ Caen Normandie, CNRS, M2C, UMR 6143, F-76000 Rouen, France

<sup>2</sup> BRGM, 3 av. C. Guillemin, 45060 Orleans Cedex 02, France

\* Email address: Asmae.ez-zahy@univ-rouen.fr

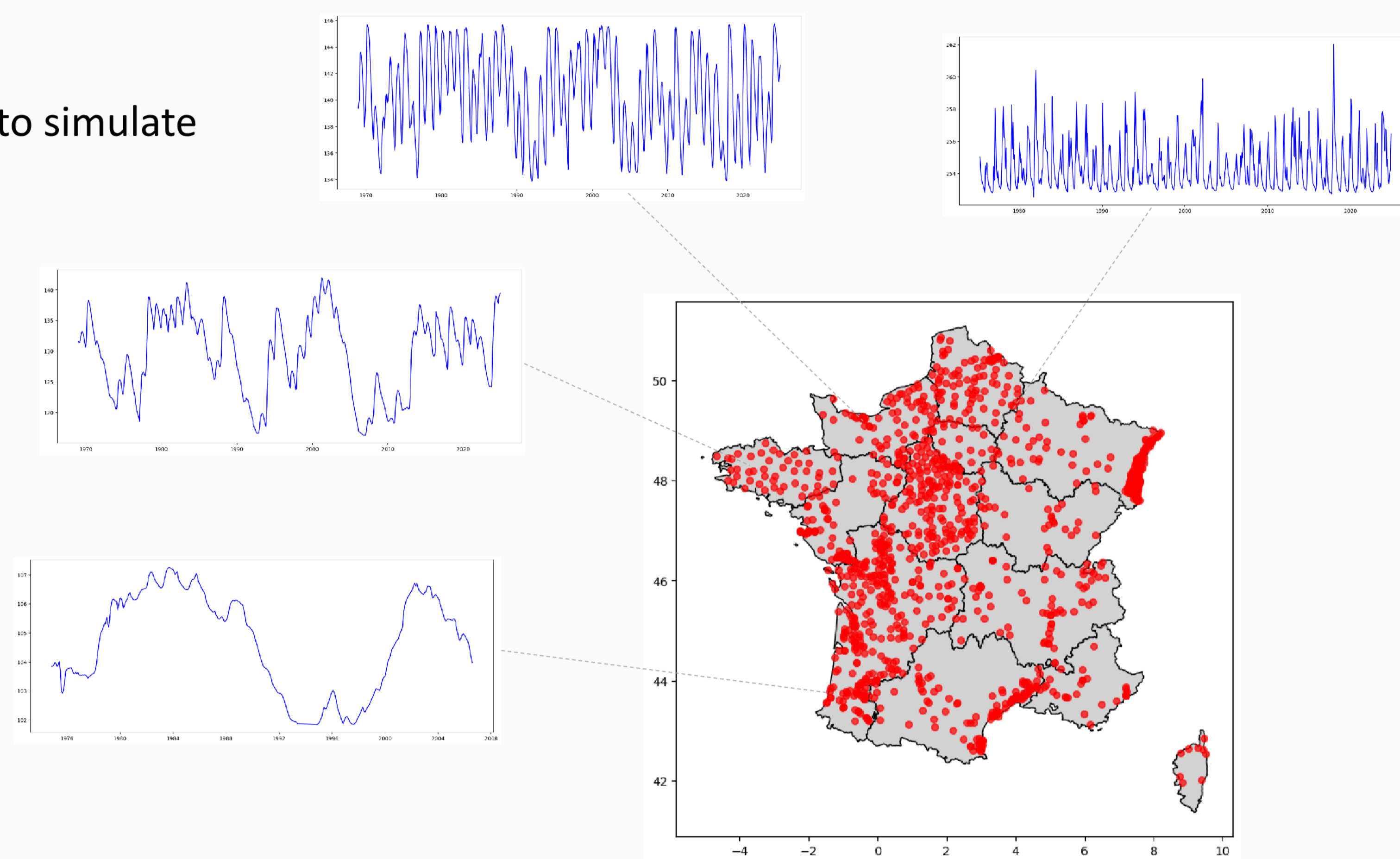
## I. Context and Objectives

Groundwater is a **critical resource** for ecosystems, agriculture, and drinking water. Simulating **groundwater level variations** over large geographic regions is essential, especially under **climate change** and growing **human pressures** such as pumping and land-use changes (Boé and Habets, 2014; Habets et al., 2015). Existing local models often capture only part of the variability and show limited **generalization** across diverse aquifers

**Deep Learning** has shown potential for simulating groundwater in simpler contexts, such as aquifers unaffected by human activity (Chidepudi et al., 2023) However, a **generalizable approach** that can handle **all types of aquifers**, including unconfined, confined, highly reactive, or inertial systems, and those influenced by human activity, is still needed.

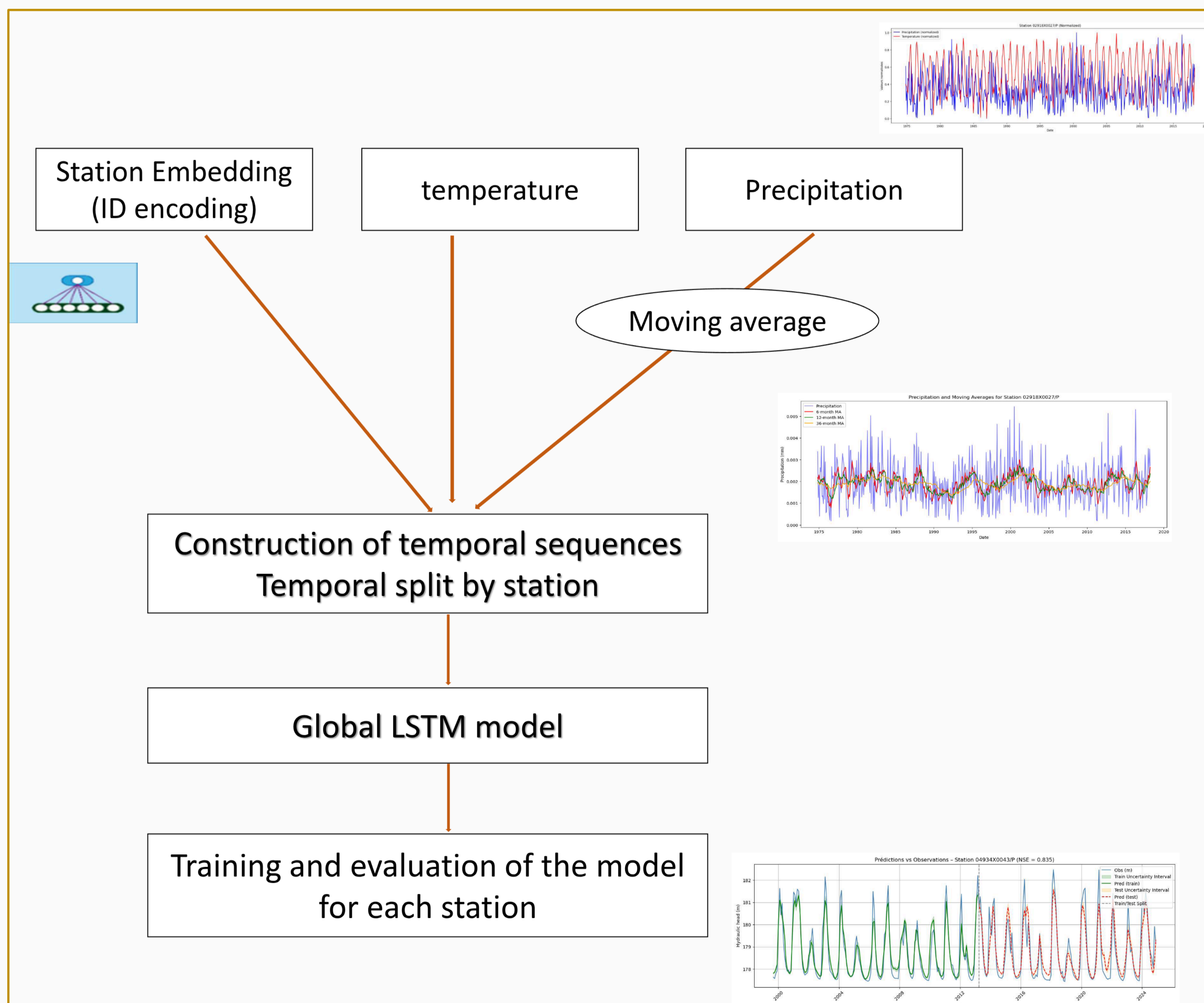
This project aims to develop a **generalizable Deep Learning framework** to simulate groundwater level variations across France, and this poster presents one of the approaches to be tested. The model will:

- Integrate **precipitation and temperature** as main drivers while capturing both shared patterns and local variability.
- Account for hydrogeological diversity** and anthropogenic influences across different aquifers.
- Identify and optimize neural network architectures** for robust, large-scale prediction.
- Provide a scalable, operational tool** to support sustainable groundwater management.



## II. Data and methodology

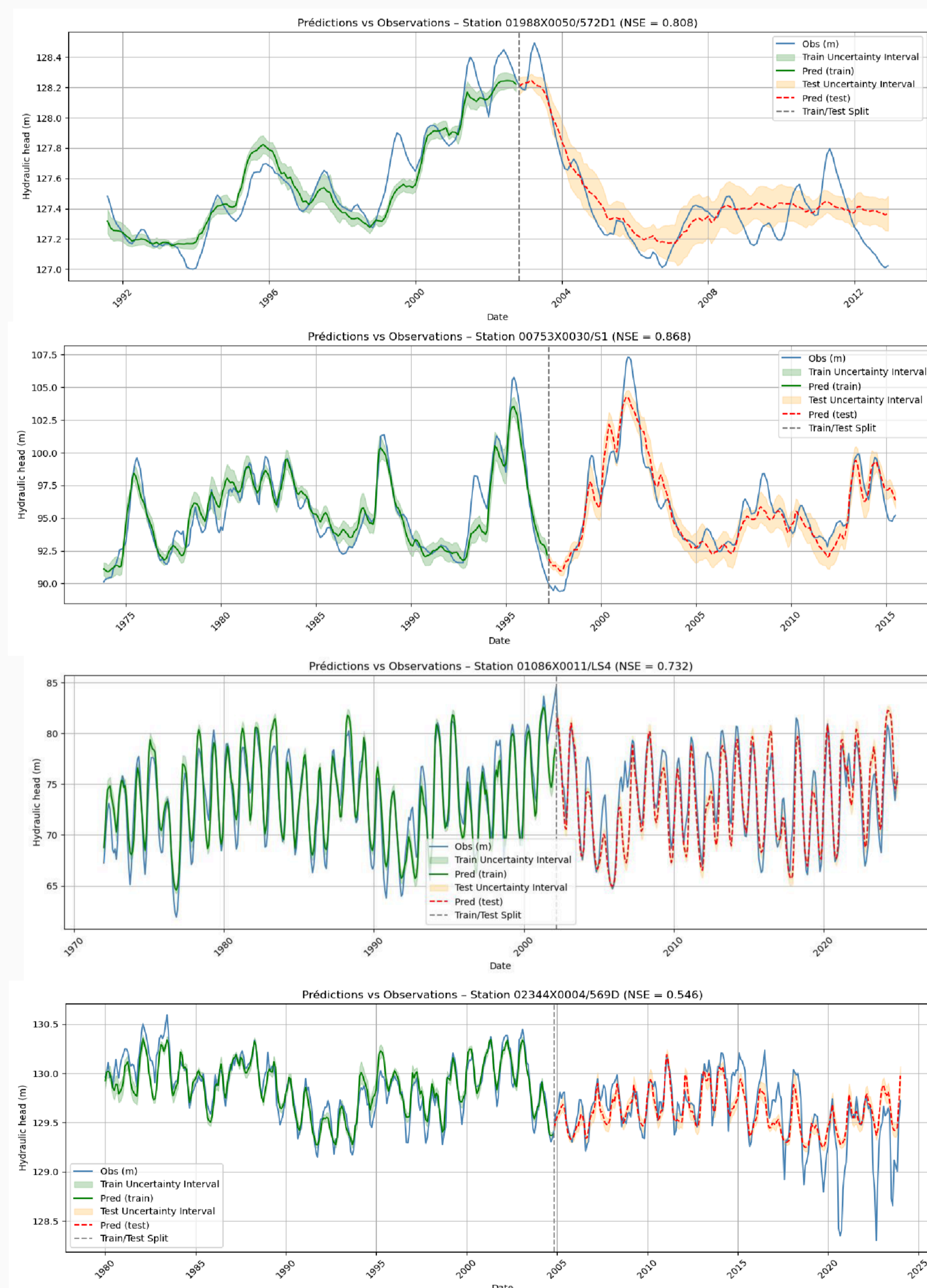
- Groundwater monitoring stations across metropolitan France with +20 years of records and minimal gaps.
- Precipitation & Temperature: ERA5 reanalysis (0.25° × 0.25° resolution).



### Key Finding

- Using station embeddings improves generalization by allowing the model to learn site-specific characteristics across diverse aquifers.
- A moving average highlights low-frequency variability in groundwater levels, helping detect long-term trends.
- The model learns different hydrogeological and climatic contexts, with further refinement needed for some site-specific characteristics.

## III. Results



### References

- Chidepudi, S. K. R., Massei, N., Jardani, A., Henriot, A. (2024). Groundwater level reconstruction using long-term climate reanalysis data and deep neural networks. *Journal of Hydrology: Regional Studies*, 51. <https://doi.org/10.1016/j.ejrh.2023.101632>
- Habets, F., Ackerer, P., Amraoui, N., Augeard, B., Besson, F., Caballero, Y., J-R de Dreuzy, P. Le Moigne, L. Longuevergne, E. Martin, T. Morel, F. Regimbeau, M. Rousseau, P. Rousseau-Gueutin, D. Thiéry, J.-M. Soubeyroux, J.-P. Vergnes et P. Viennot (2015). *Aqui-FR, un système multi-modèle hydrogéologique à l'échelle nationale*. *Géologues*, (187), 105-109
- Boé, J. and Habets, F.: Multi-decadal river flow variations in France, *Hydrol. Earth Syst. Sci.*, 18, 691–708, <https://doi.org/10.5194/hess-18-691-2014>, 2014.