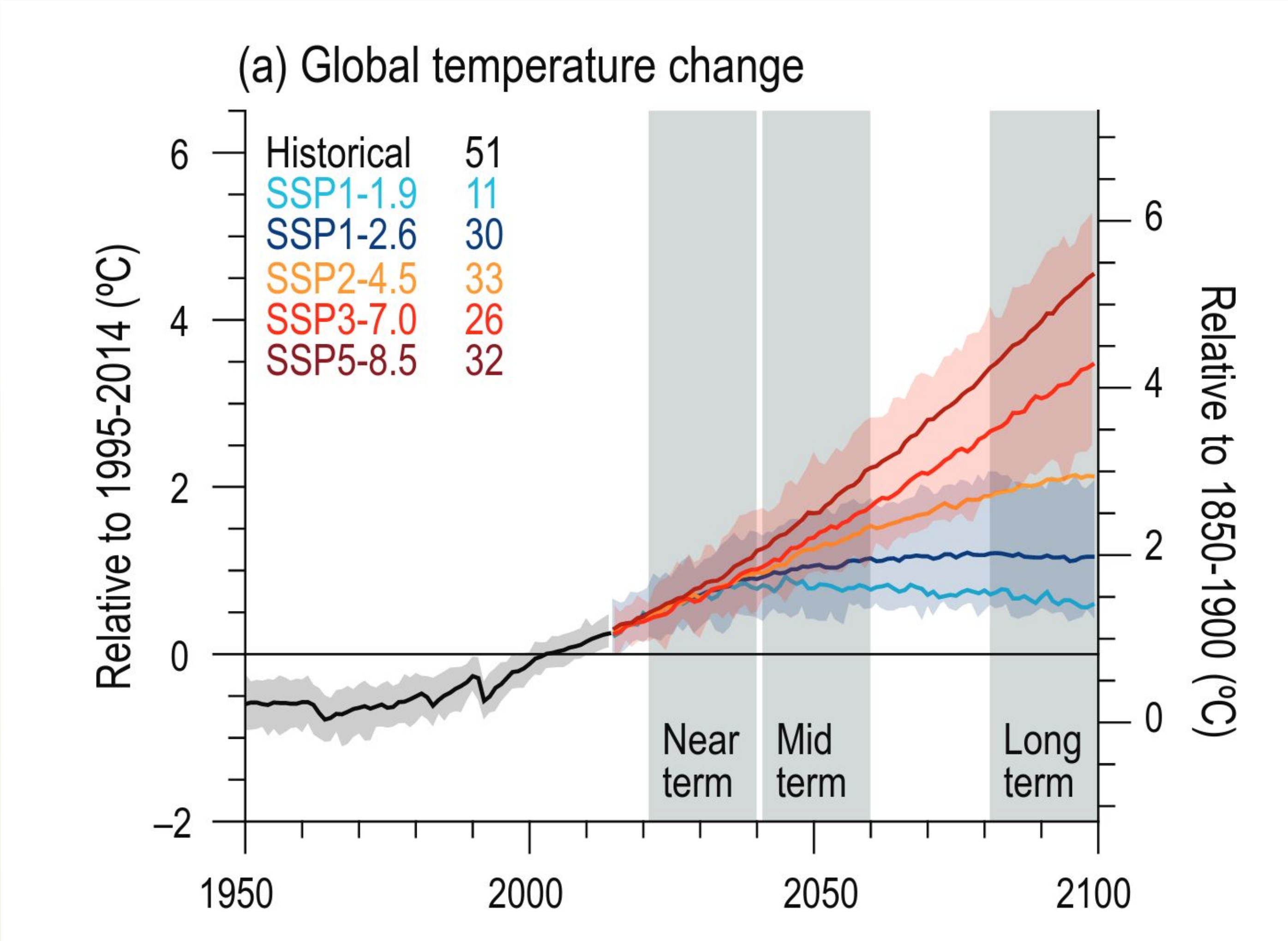
Modeling water and energy fluxes in the Seine basin

Deniz Kilic, Agnès Rivière, Nicolas Flipo, Agnès Ducharne, Nicolas Gallois, Shuaitao Wang and Philippe Peylin

Evolution of air temperatures



Projected temperature change, relative to 1995-2014 mean temperature [IPCC, AR6,C4 2021]

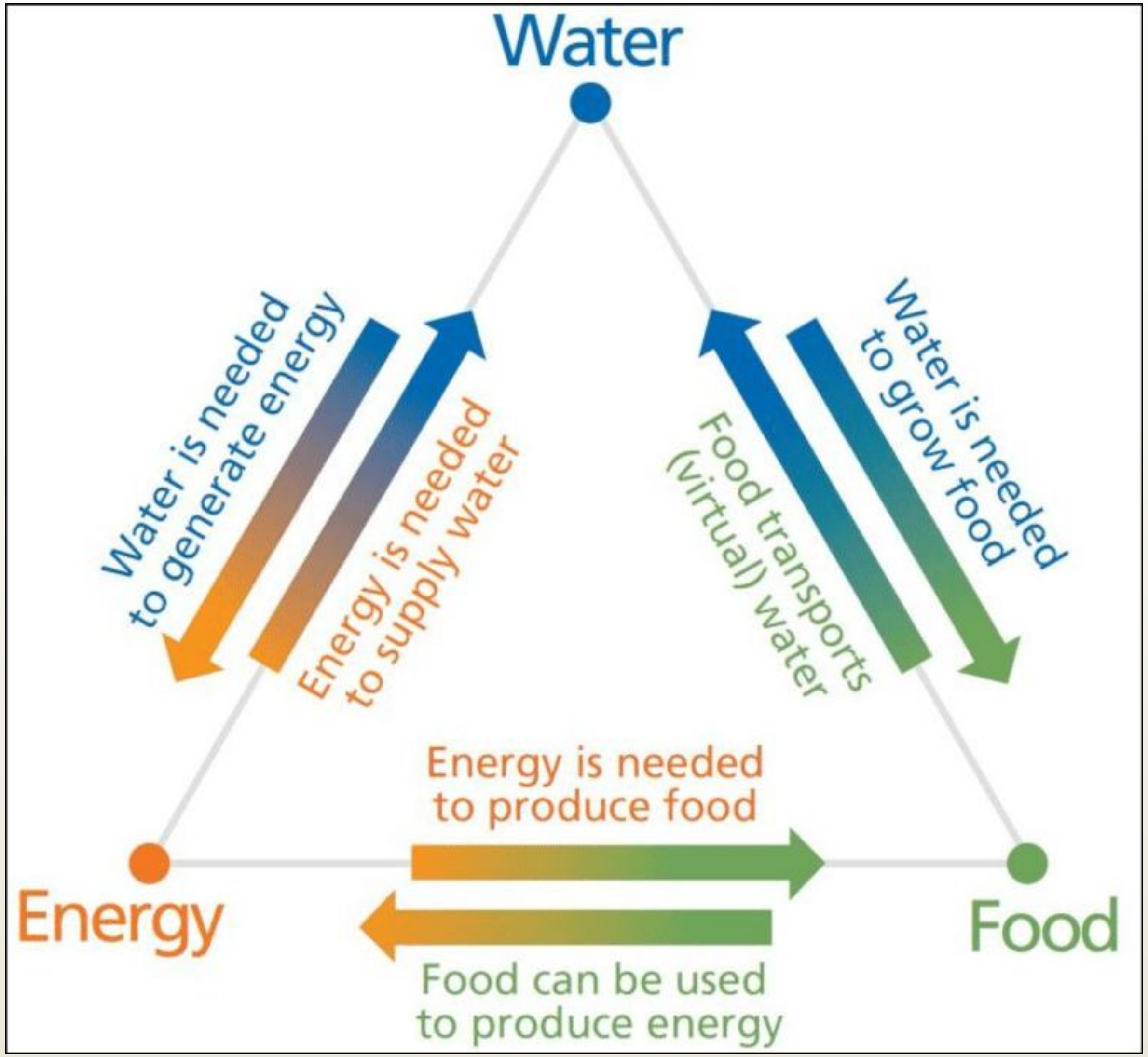
Resilience under climate change

- Water, energy and nutrient cycles are interconnected

- Essential resources (socio-economic and biodiversity)
    - Limited resources
    - Competitive usage

→**Water, Energy, Food Nexus**

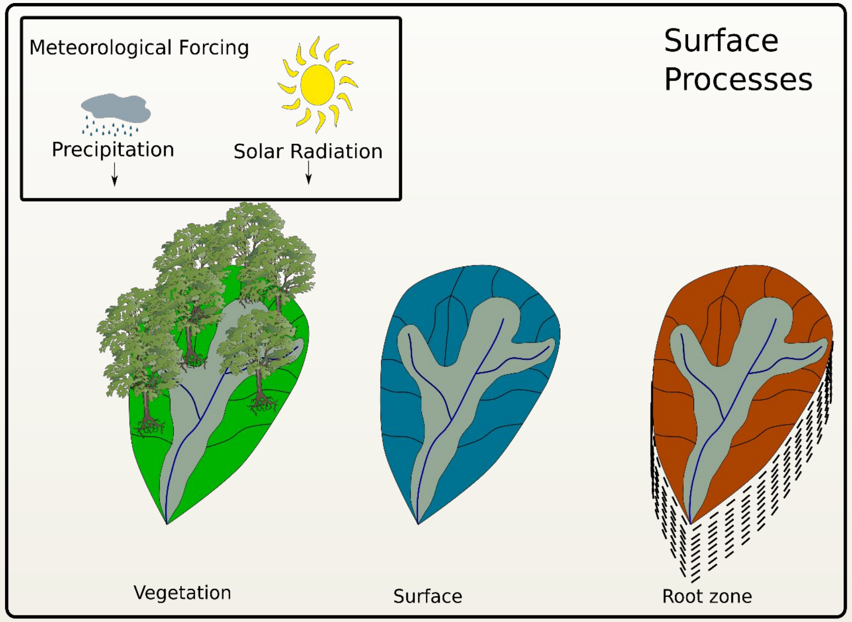
Forum Economique Mondial de Davos en 2011



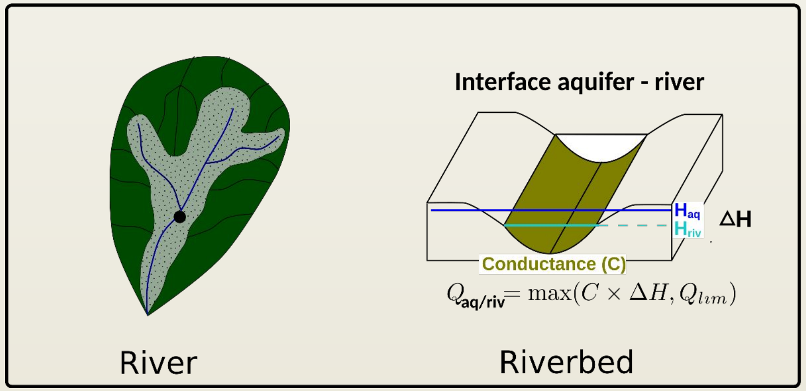
[Klingbeil and Byiringiro, 2013]

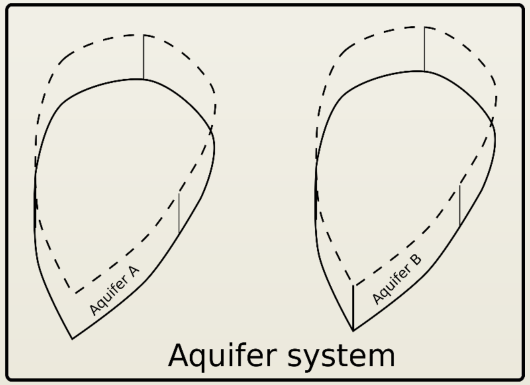
Development of a coupled modeling platform

- ORCHIDEE (tag2.2,rev6309)



- CaWaQS (v3.0)

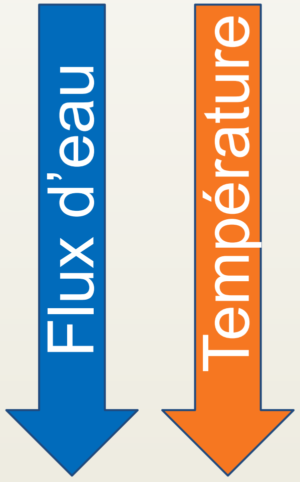




Offline coupling

- ORCHIDEE > CaWaQS :
  - No groundwater to atmosphere feedback
  - Daily time step

ORCHIDEE



CaWaQS

Water fluxes:

Runoff > River

Drainage > Aquifer recharge

Temperature:

Soil bottom > Recharge

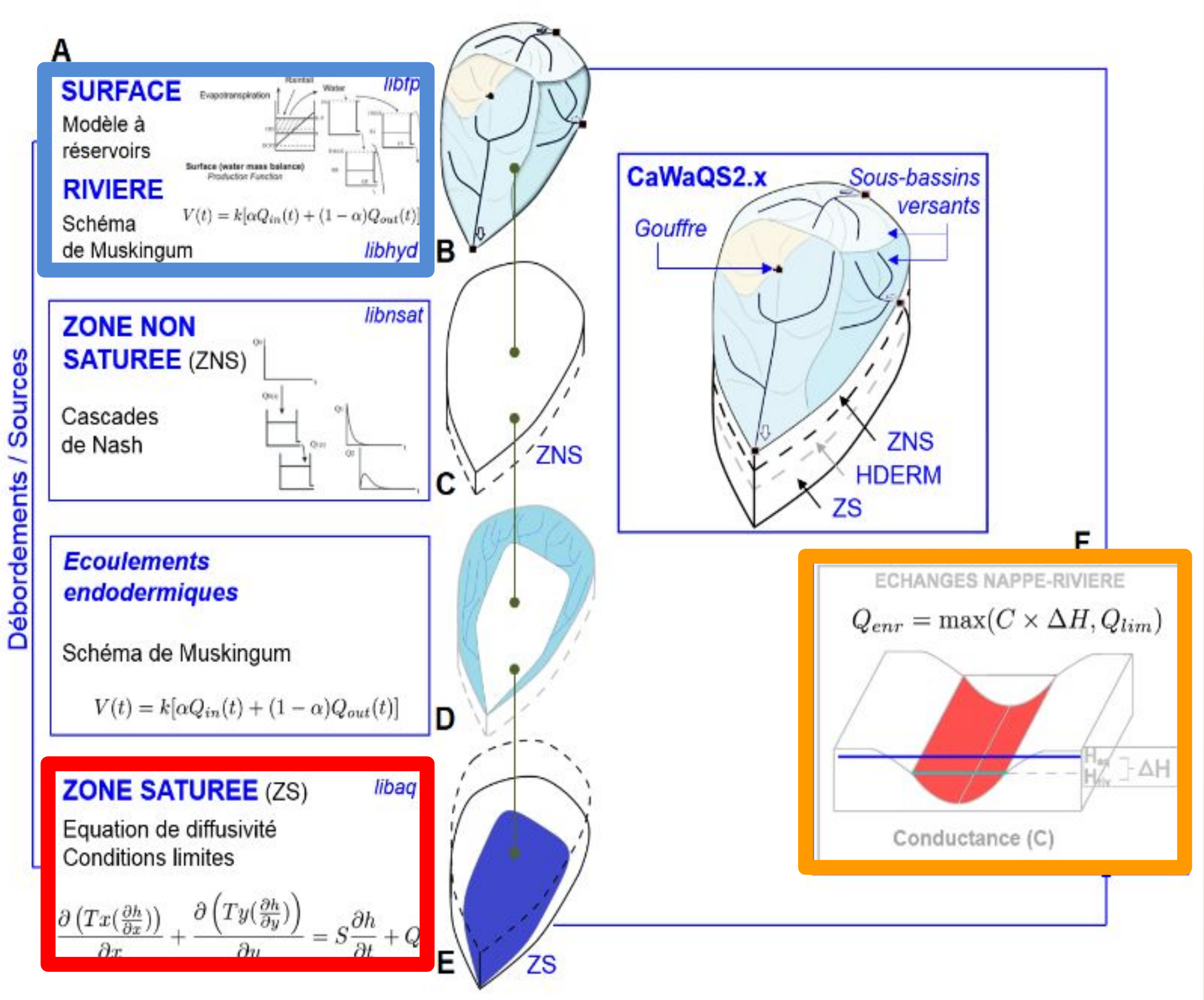
Soil surface > Runoff

Soil surface > Streams below Strahler order < 3

Heat transport in the aquifer system and river network

- Heat transport in the whole hydrosystem
  - Libttc for aquifer and river
  - Coupling of libttc for every hydrosystem compartment

- Energy fluxes at interfaces
  - Air-River
  - Aquifer-River
  - Aquitards



Reactivity through interfaces

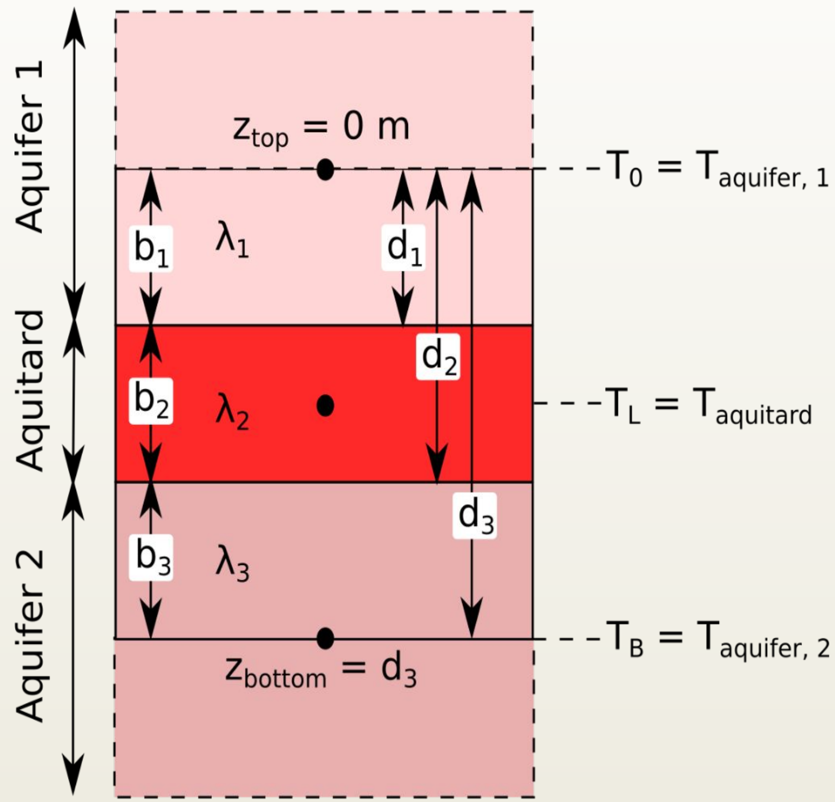
- Analytical solution of Kurylyk et al. 2017 :
  - Advection : drainance
  - Conduction : properties of each layer

$$T_i(z) = C_{i1} \exp\left(\frac{qz}{\gamma_i}\right) + C_{i2} \quad (i = 1, 2, ..., n)$$

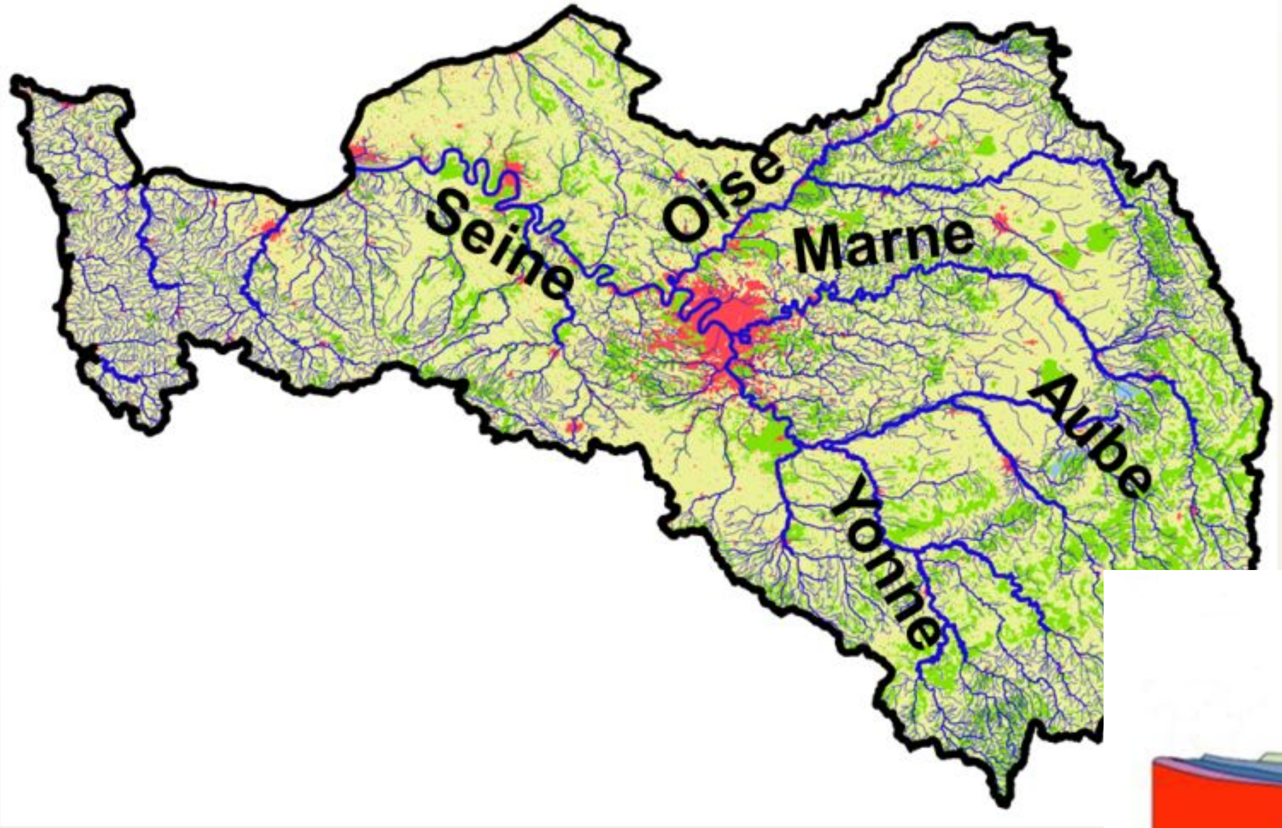
$$C_{i2} = \frac{aT_0 - T_B}{a-1} \quad (i = 1, 2, ..., n) \qquad C_{1,1} = \frac{T_B - T_0}{a-1}$$

$$C_{(i+1)1} = \exp\left\{qd_i\left(\frac{1}{\gamma_i} - \frac{1}{\gamma_{i+1}}\right)\right\}C_{i1} \quad (i = 1, 2, ..., n-1)$$

  - Assumptions similar to water fluxes model :
    - 1-D : Aquitard > low lateral fluxes
    - Steady state at each time step

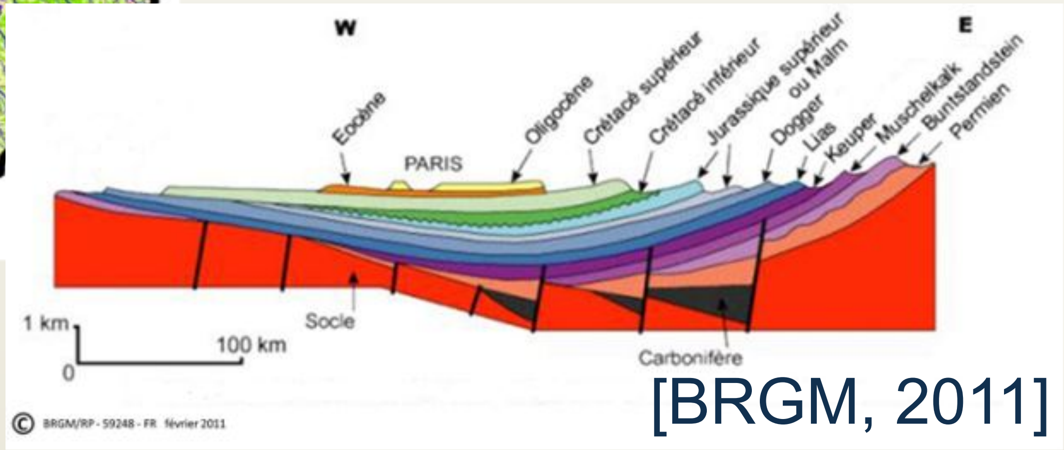


The Seine basin



In numbers :

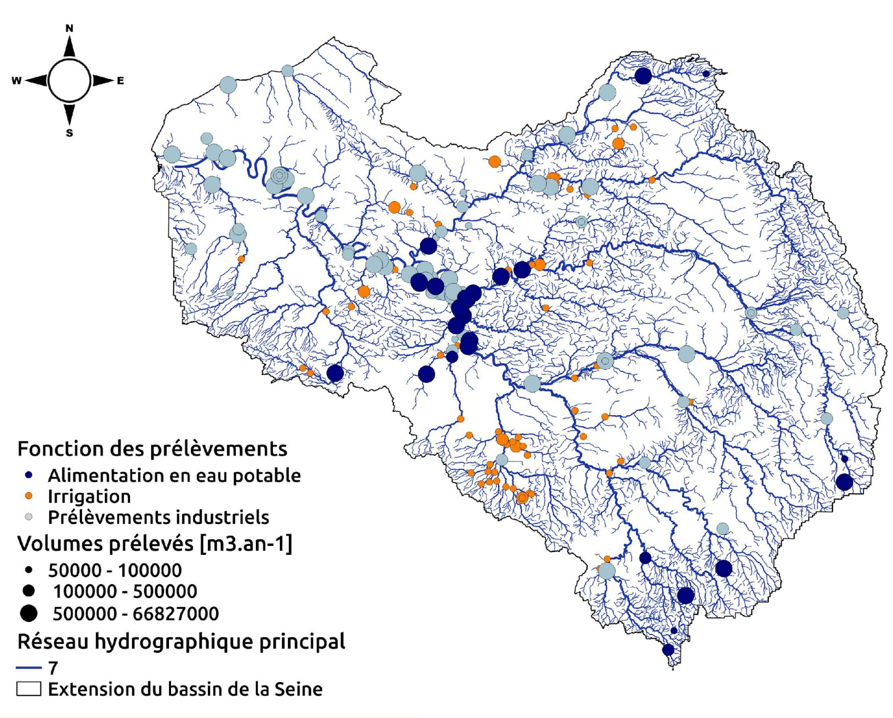
- Basin with 76 286 km²
- 28 000 km of rivers
- 20 M inhabitants



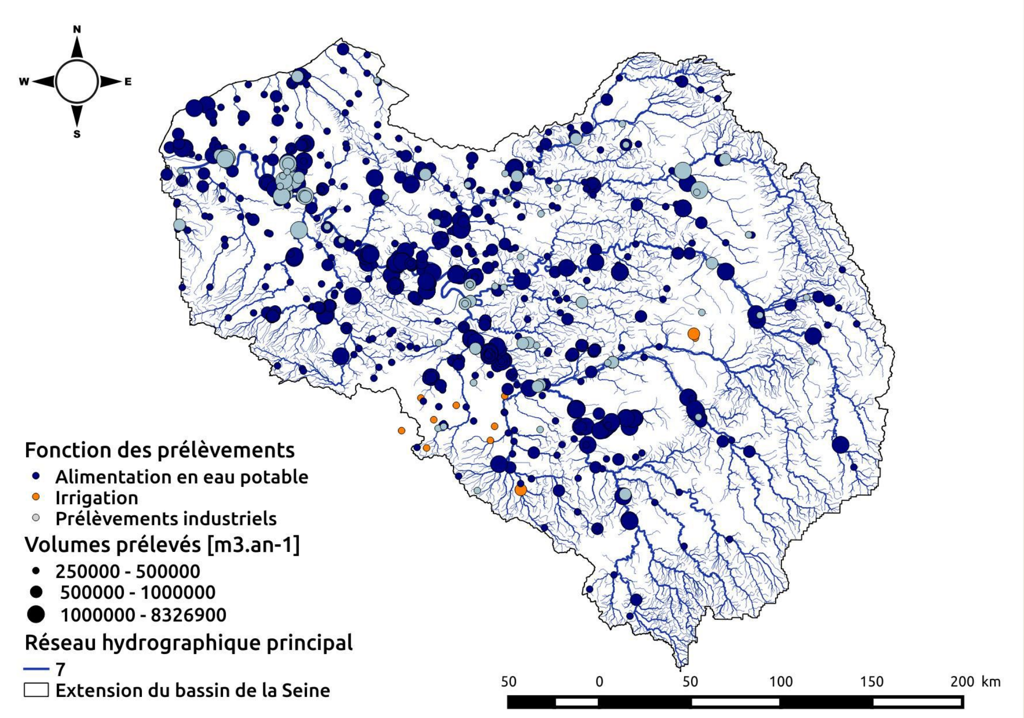
[BRGM, 2011]

Stress on the water resources: Abstractions up to 3 km^3/a

Surface water resources: 2 km^3 / a



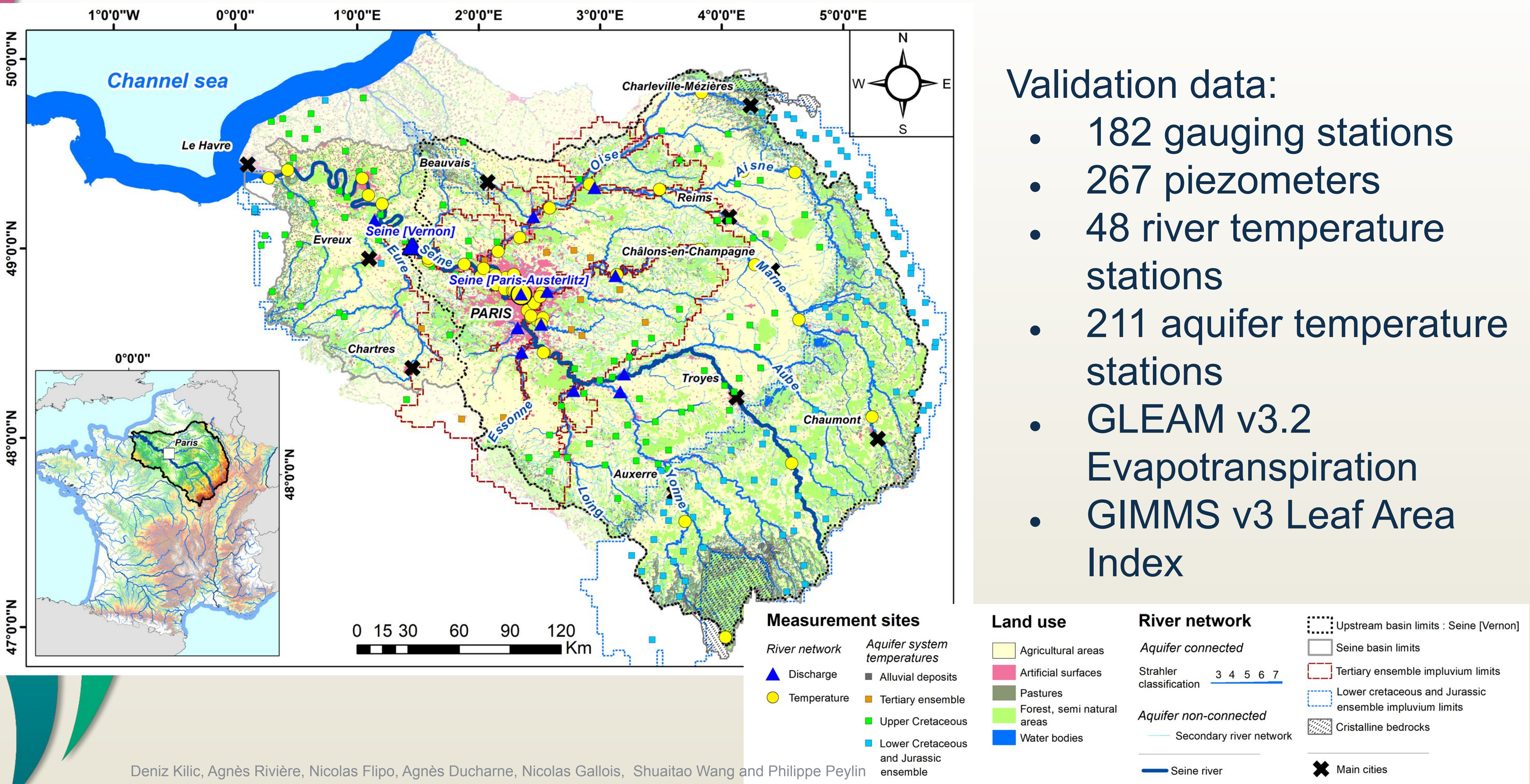
Aquifer system : 1 km^3 / a



The numerical application

- **ORCHIDEE**
  - 1490 Safran cells at 8 km horizontal resolution, hourly
  - 11 soil layers, 2 m > Unsaturated zone
  - Offline mode (30 minutes time step)
- **CaWaQS**
  - Aquifer system
    - 8 Aquifer layers
    - 107610 Aquifer cells (Nested cells, ~400m)
    - Properties from the literature [Gallois et al. 2021, Denzer, 2016, Riviere, 2012]
  - River
    - 26804 river cells (~1000 m)
    - Properties from the literature [Gallois et al. 2021]

Calibration of the platform



Validation data:

- 182 gauging stations
- 267 piezometers
- 48 river temperature stations
- 211 aquifer temperature stations
- GLEAM v3.2 Evapotranspiration
- GIMMS v3 Leaf Area Index

3 Calibration of surface water balance - ORCHIDEE

Calibration period: 2001 - 2018
Objective function:

- Minimize bias on discharge
- Effective rainfall partition [Flipo et al., Submitted]

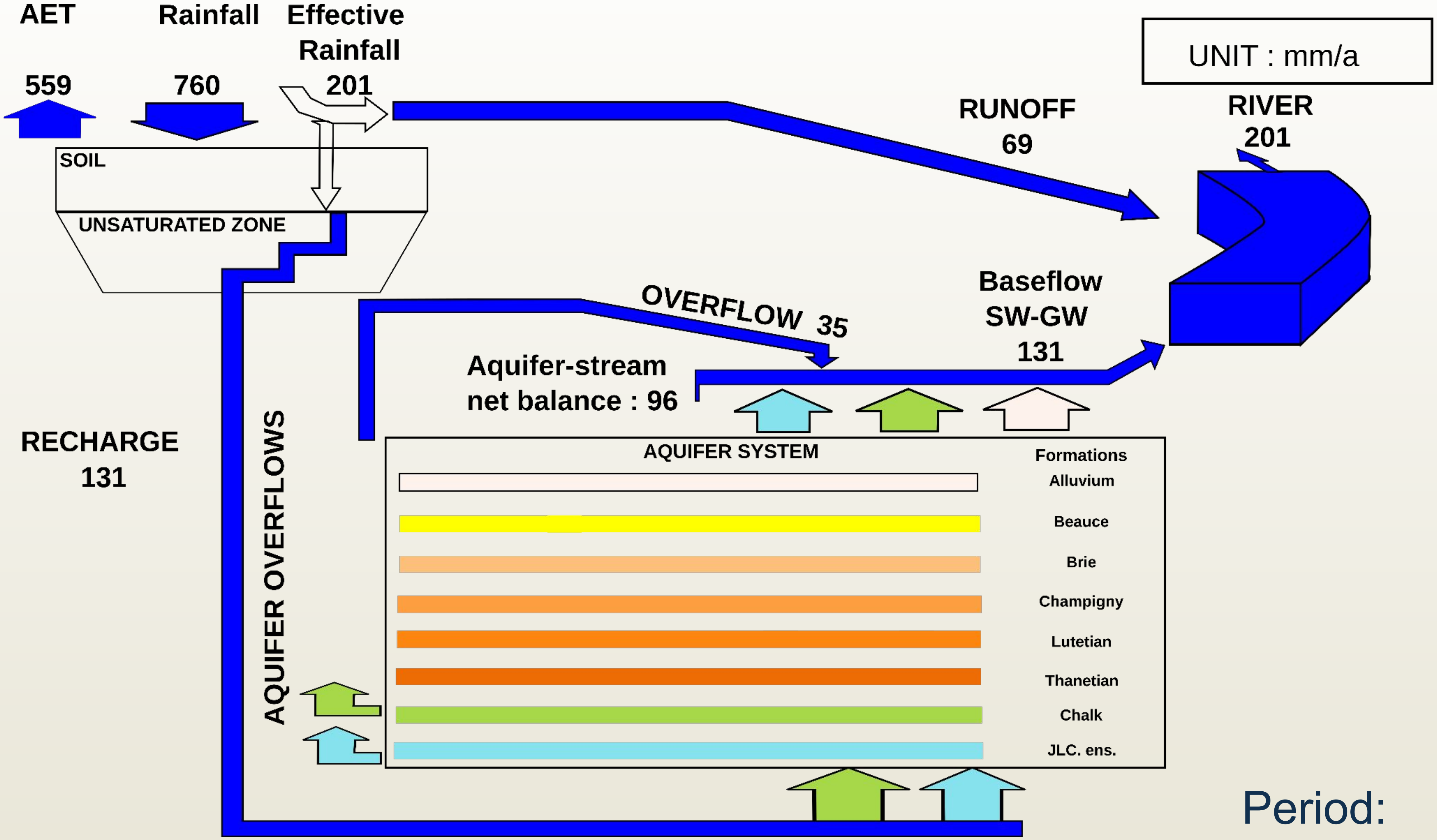
A total of 32 parameters are calibrated:

- Soil Maps (Reynolds, LUCAS, INRA, SoilGrids)
- Vegetation parameters
- Albedo & aerodynamic resistance related parameters
- Soil parameters

Number of simulation performed: 10

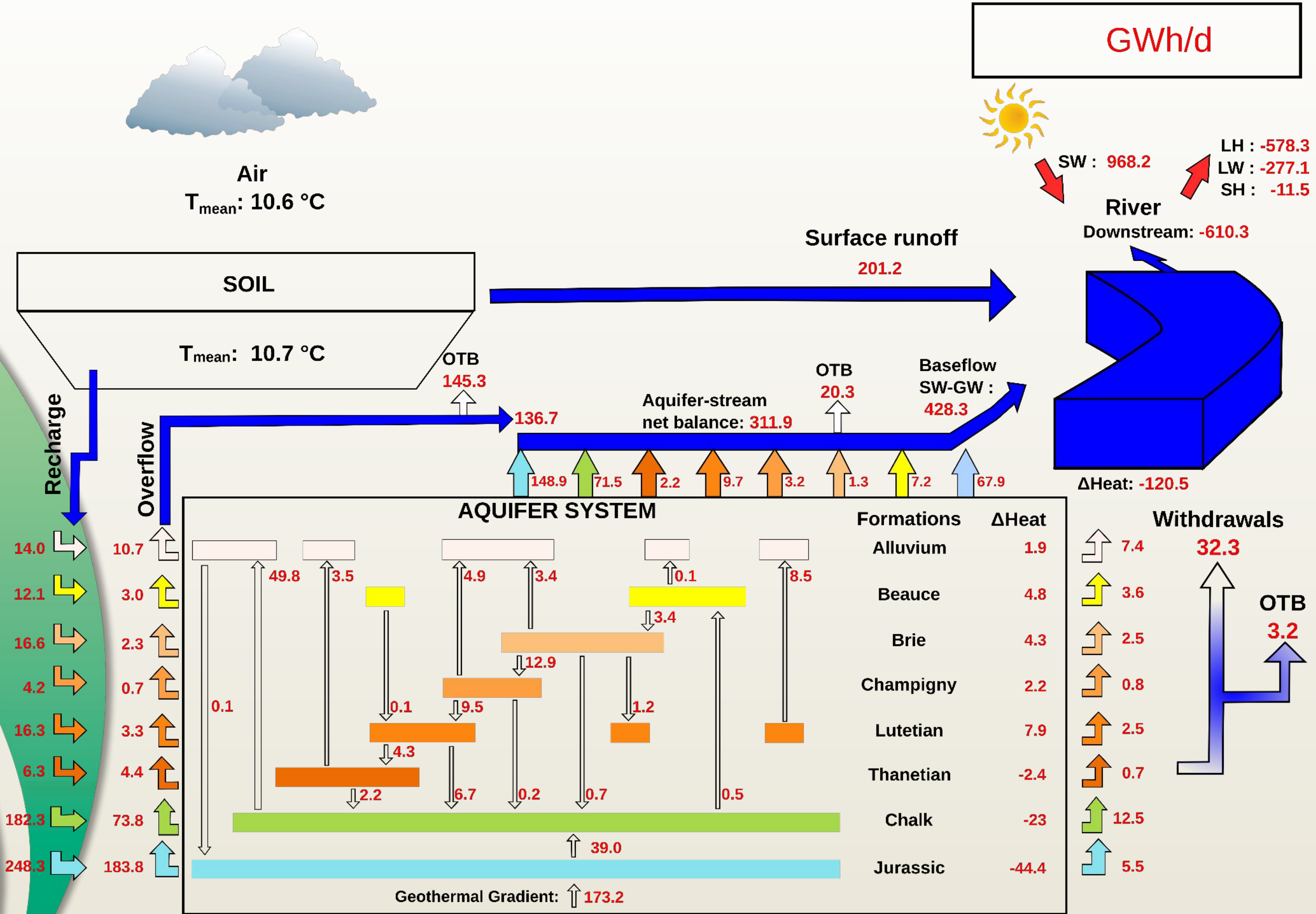
- Post processing to remove GW pumping based on the data from AESN

Hydrological functioning: Dominant fluxes



Period: 2001-2018

Thermal functioning: Heat budget



- Advective fluxes dominate shallow aquifer heat transport
- River-aquifer heat transport is controlled by advective fluxes

Period: 2001-2018

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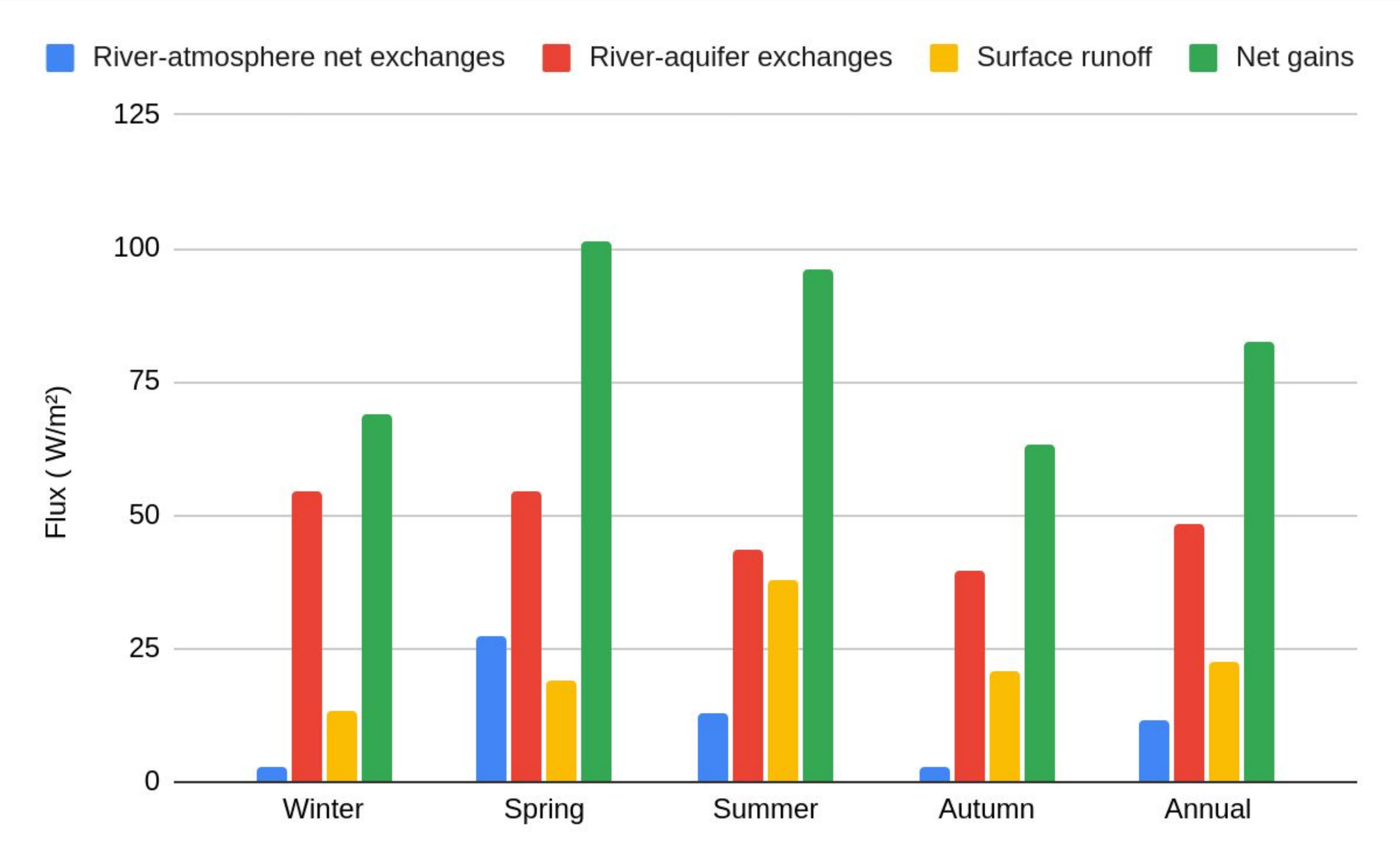
Thermal functioning: River



Net river-atmosphere exchanges are less than river-aquifer exchanges

Latent heat is the largest heat sink

Streambed advection is the largest heat flux source

Conclusions

A modeling tool to quantify energy and water fluxes in a regional catchment was developed

- Adaptation of **ORCHIDEE SVAT** at **regional scale**, calibration
- First **complete water and energy budget** at regional scale including the aquifer system and the river network in **the Seine basin**

The Seine river temperature regime is **controlled** by:

1. **Stream-aquifer advective flux**
2. **Surface runoff**
3. **River-atmosphere net exchanges**

Perspectives

- Ongoing work :
  - Simulations with scenarios from the IPCC
  - Online coupling

- Improved policy-making decisions with scenario-testing capabilities

- Making decision on water allocation:
  - Competitive use of water resources (irrigation, drinking, energy, food production, ecosystem)
  - Adding groundwater and geothermal into the Water, Energy, Food Nexus

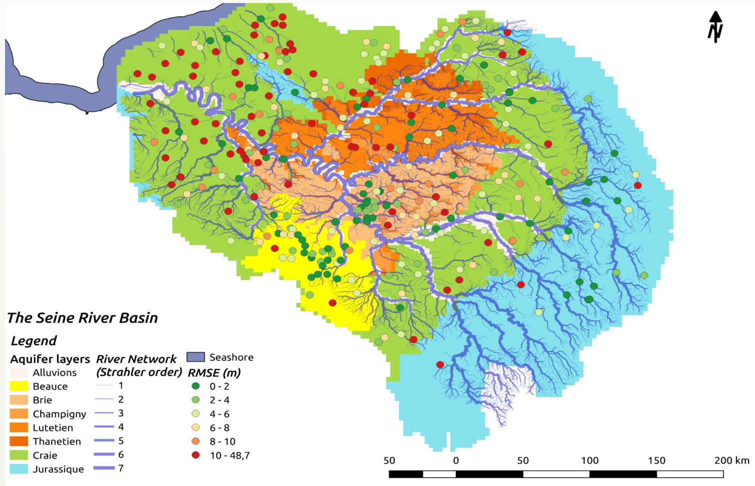
Évaluation des flux d'eau et de chaleur sur l'ensemble de l'hydrosystème Seine

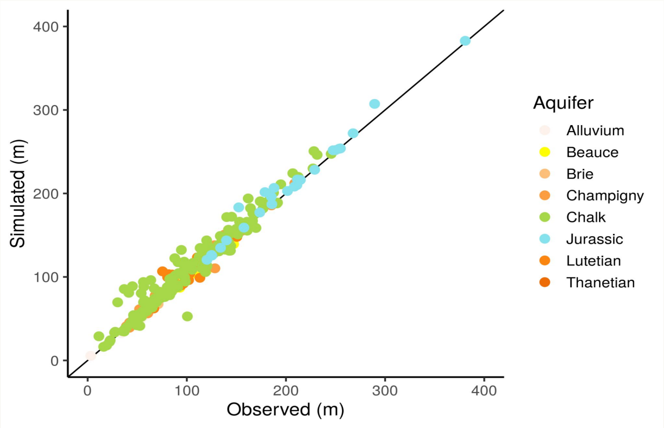
Merci beaucoup !
Thank you !
Tesekkurler !

More details at: Kilic, D., Rivière, A., Gallois, N., Ducharne, A., Wang, S., Peylin, P., & Flipo, N. (2023). Assessing water and energy fluxes in a regional hydrosystem: case study of the Seine basin. *Comptes Rendus. Géoscience*, *355*(S1), 1-21.

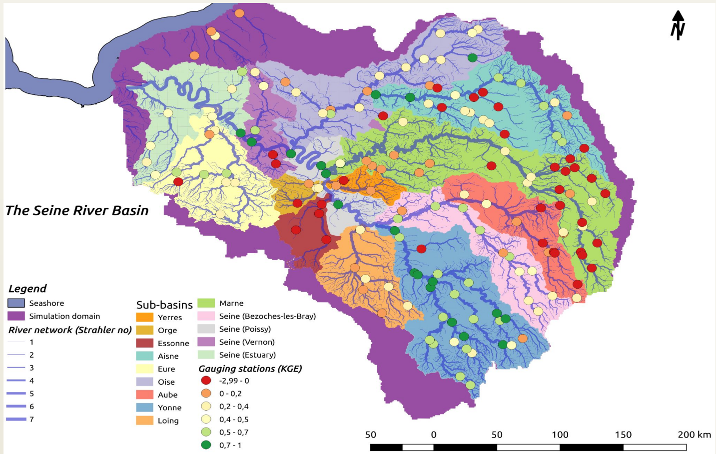
Calibration

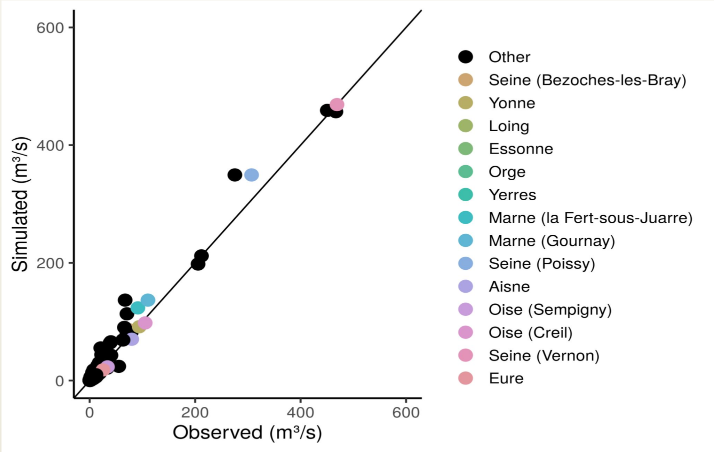
- Discharge



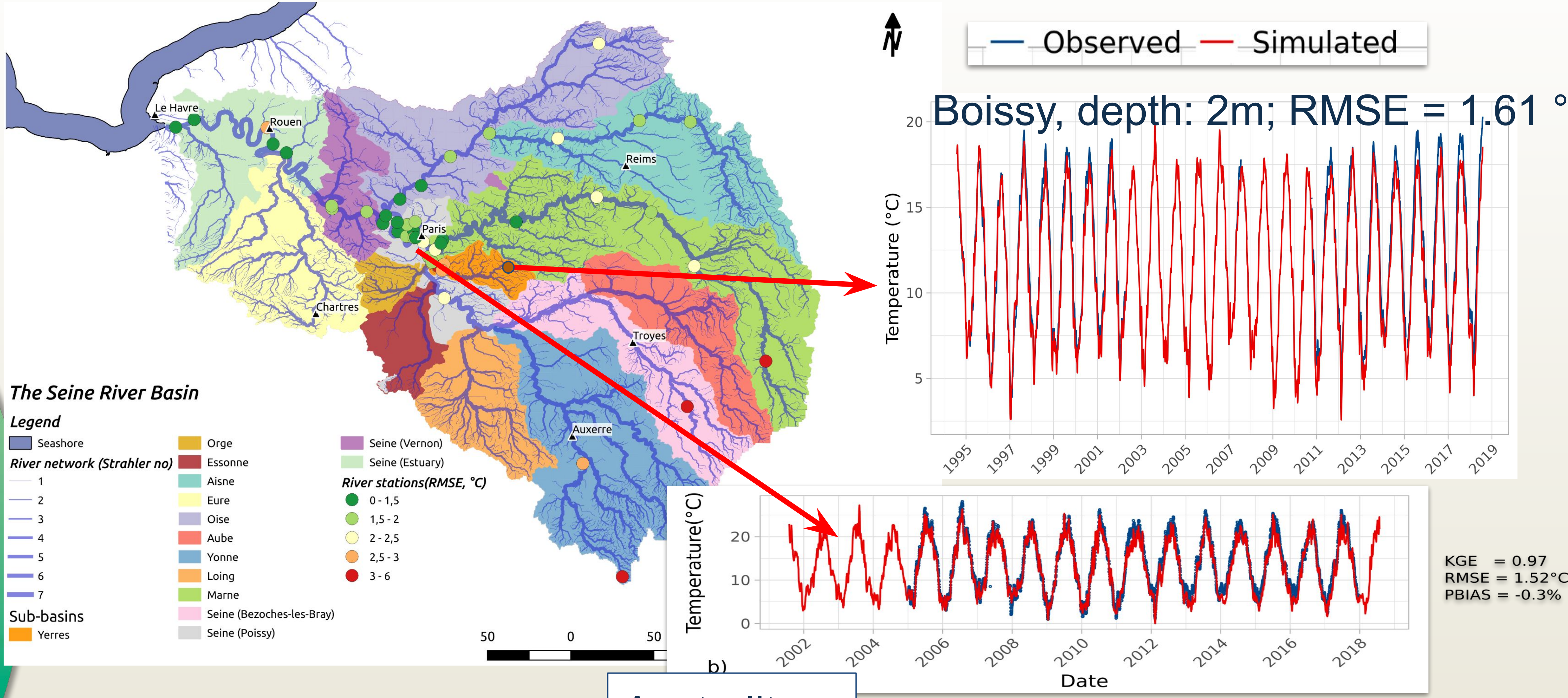


- Hydraulic head





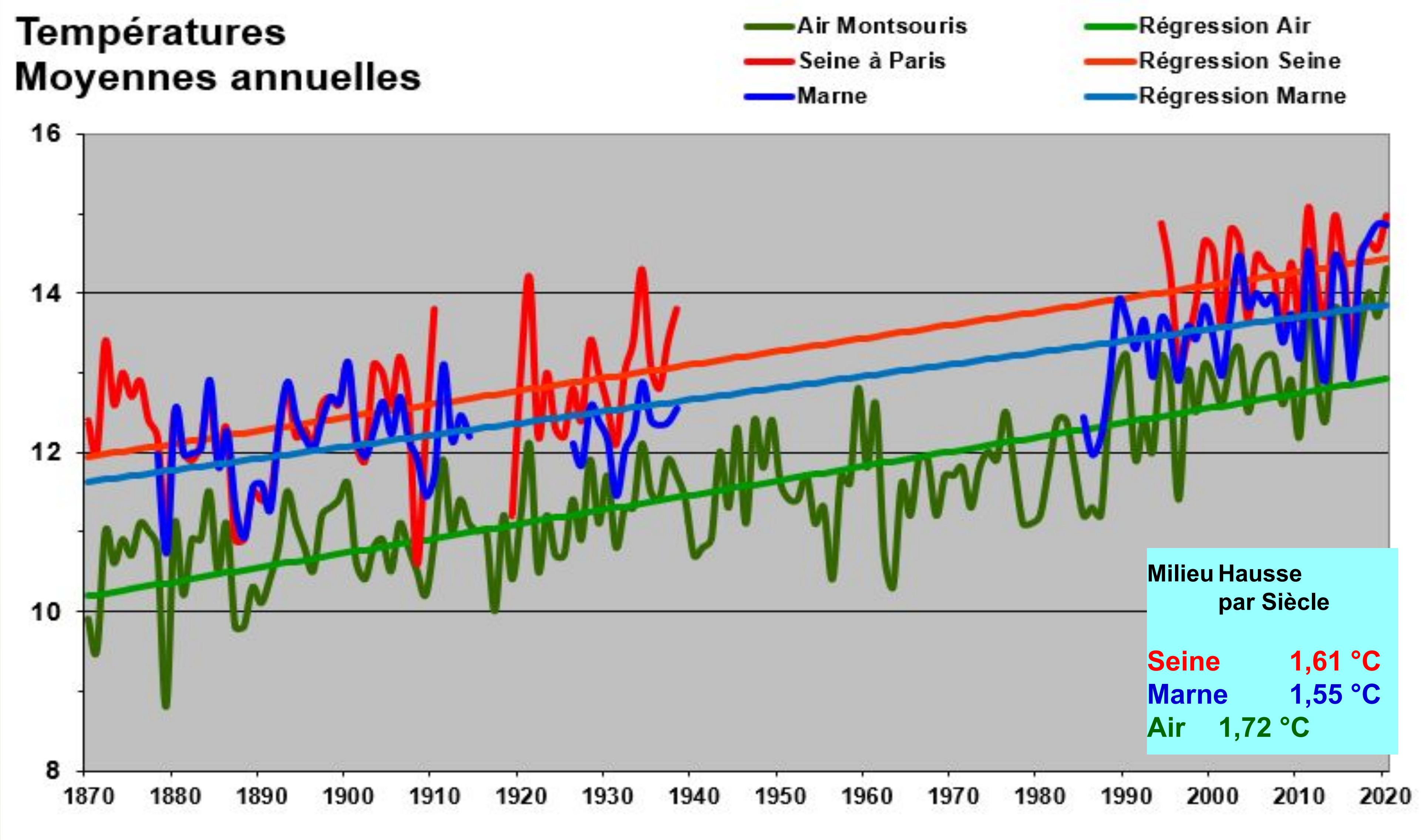
Simulation of temperatures



KGE = 0.97
RMSE = 1.52°C
PBIAS = -0.3%

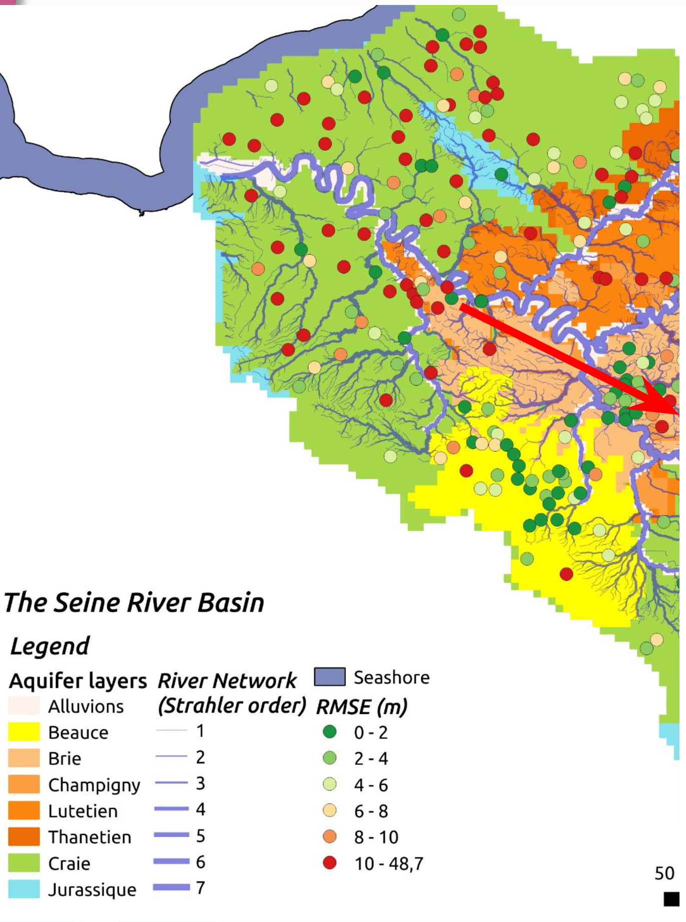
Austerlitz

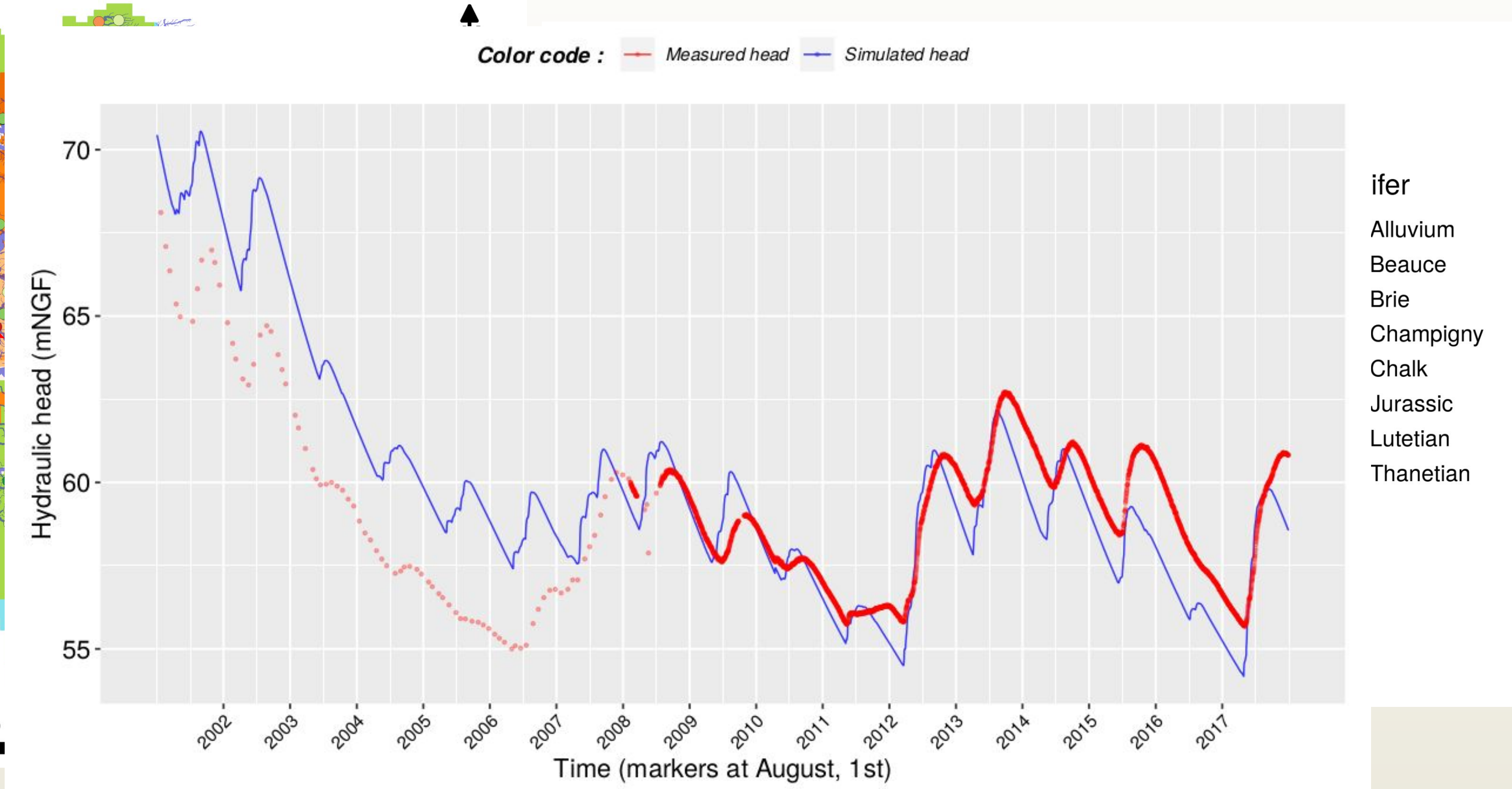
Significant temperature trend in 150 years!



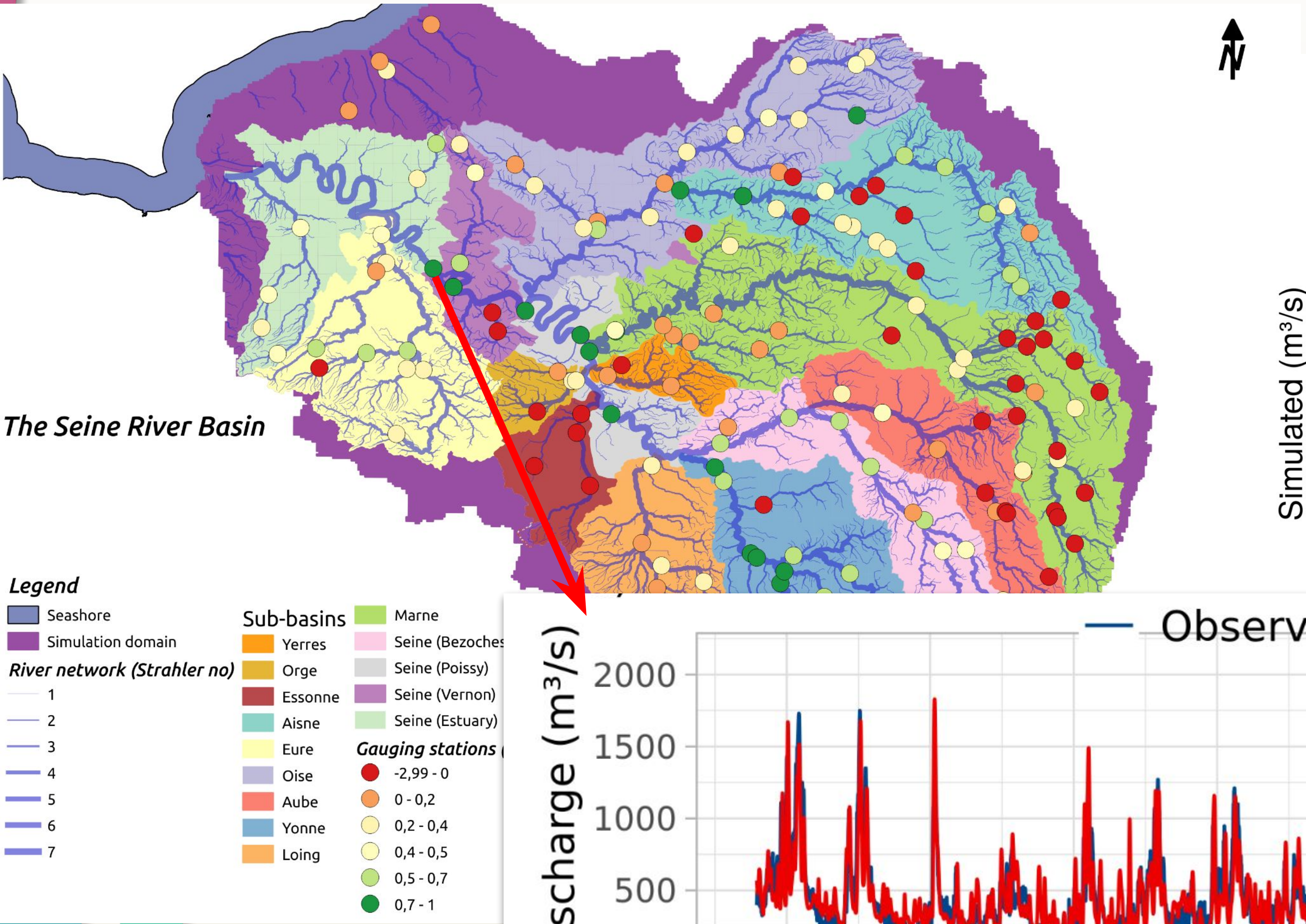
[Thomas et Rivière, 2021]

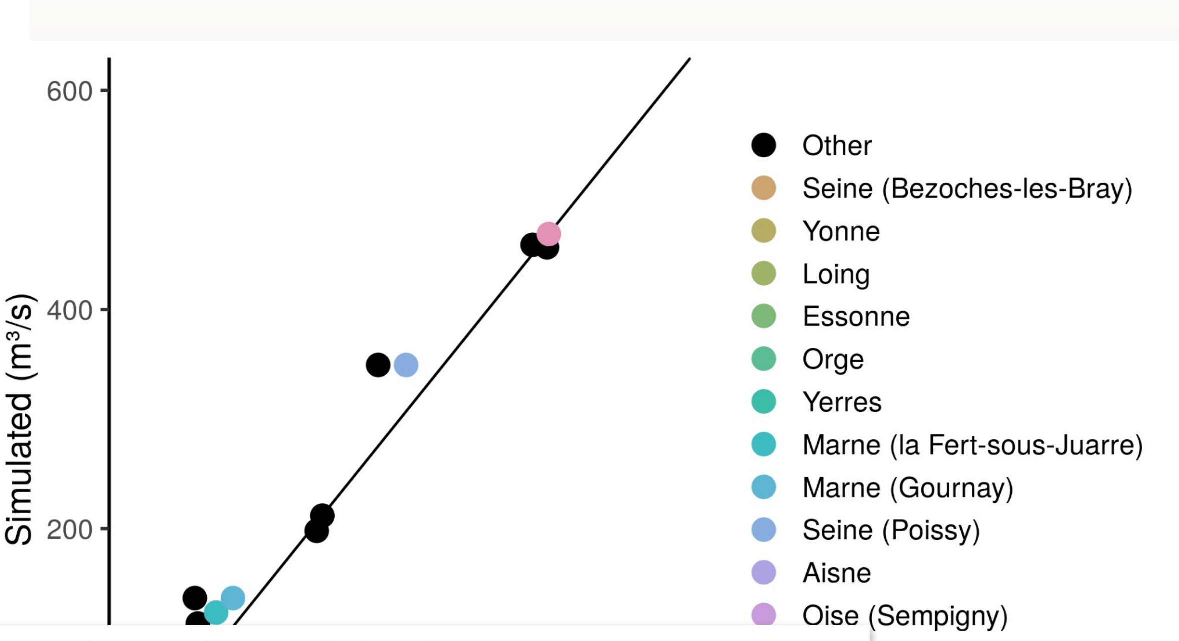
3 Simulation of the water table by CaWaQS

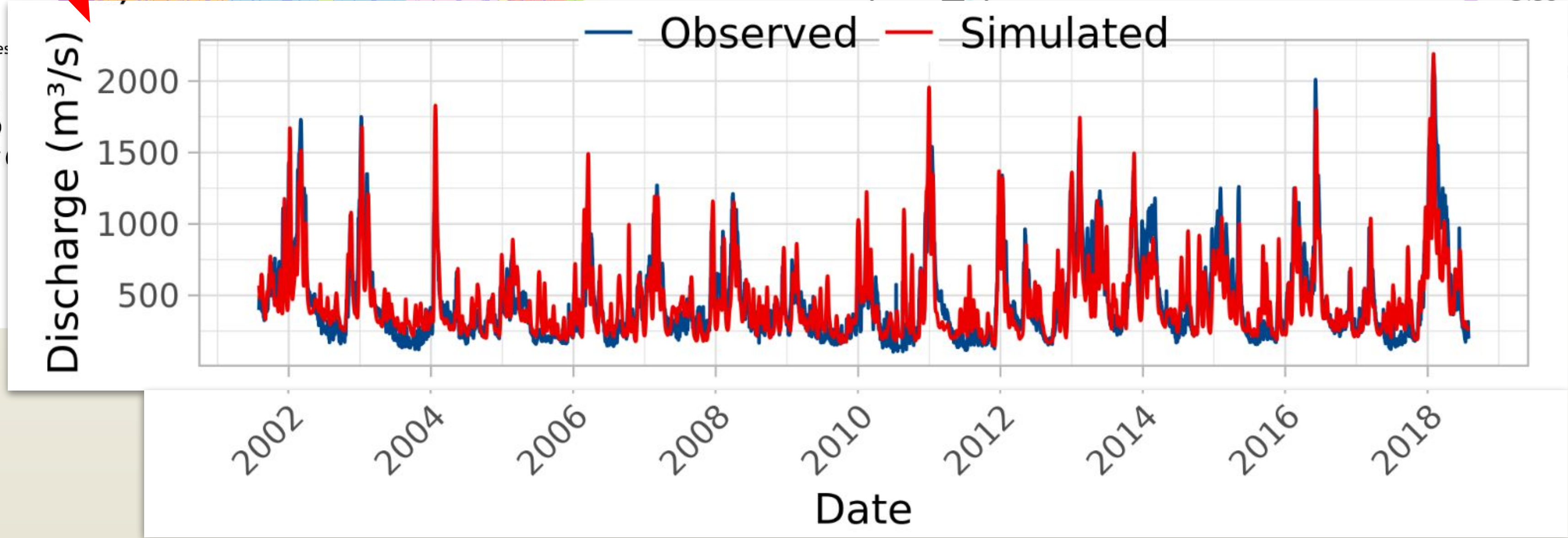




3 Simulation of discharge by ORCHIDEE-CaWaQS





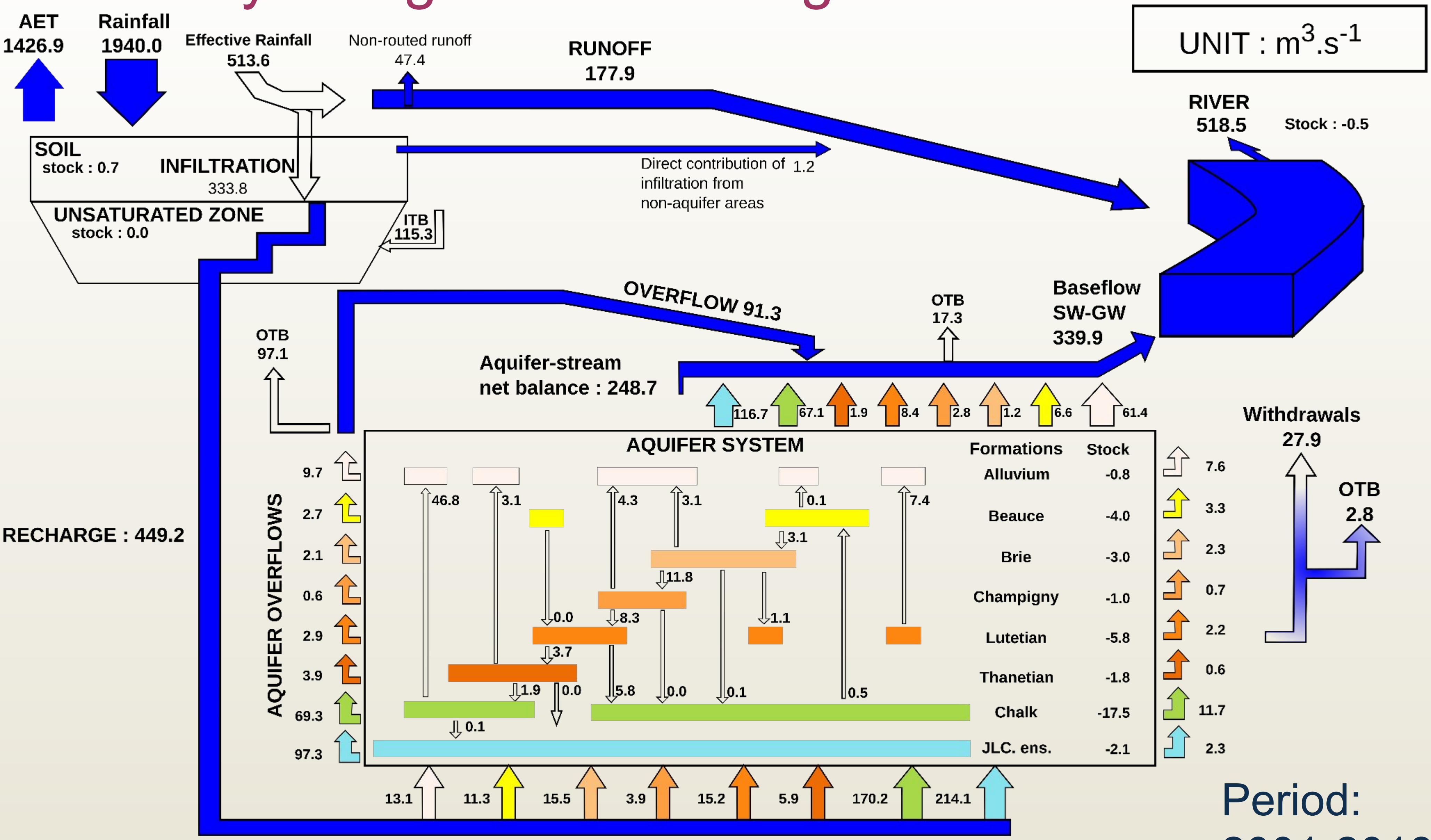


KGE = 0.77

$C_{pearson}$ = 0.82

PBIAS = 1.6%

4 Hydrological functioning: Water balance



Period:
2001-2018