INTERNATIONAL MEUSE SYMPOSIUM

© LOTERR

12th International Meuse Symposium, Liège, 9 September 2026

Towards semi-distributed modelling for low-flow simulation: comparing four hydrological models in the French Meuse catchment

Hajar El Khalfi[1], Camille Brun[2], Alban de Lavenne[3], Claire Delus[1], Didier François[1], Thibault Hallouin[4], Frédéric Hendrickx[2], Shu-Chen Hsu[3], Céline Monteil[2], Jean-Pierre Vergnes[4]

1 - Université de Lorraine, LOTERR, Metz, France

2 - EDF R&D, LNHE, Chatou, France

3 - INRAE, HYCAR, Antony, France

4 - BRGM, Orléans, France

CIPRHES

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

EDF

INRAE

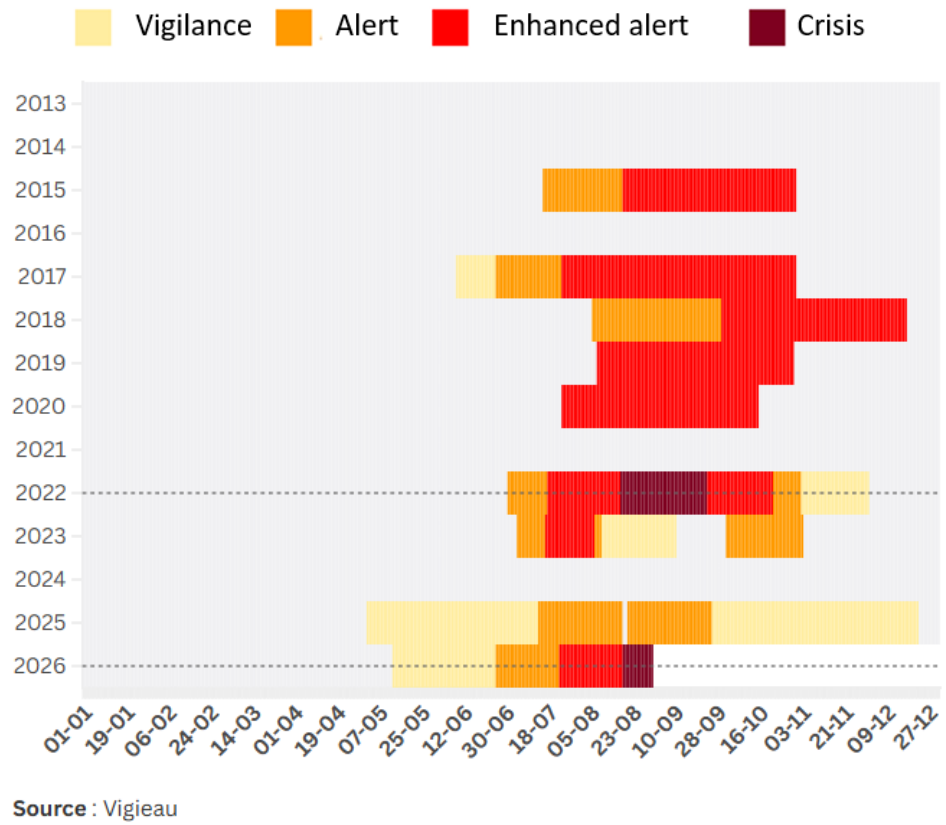
UNIVERSITÉ DE LORRAINE Membre d'UNYS

Géosciences pour une Terre durable brgm

METEO FRANCE À VOS CÔTÉS, DANS UN CLIMAT QUI CHANGE

Context and Objectives

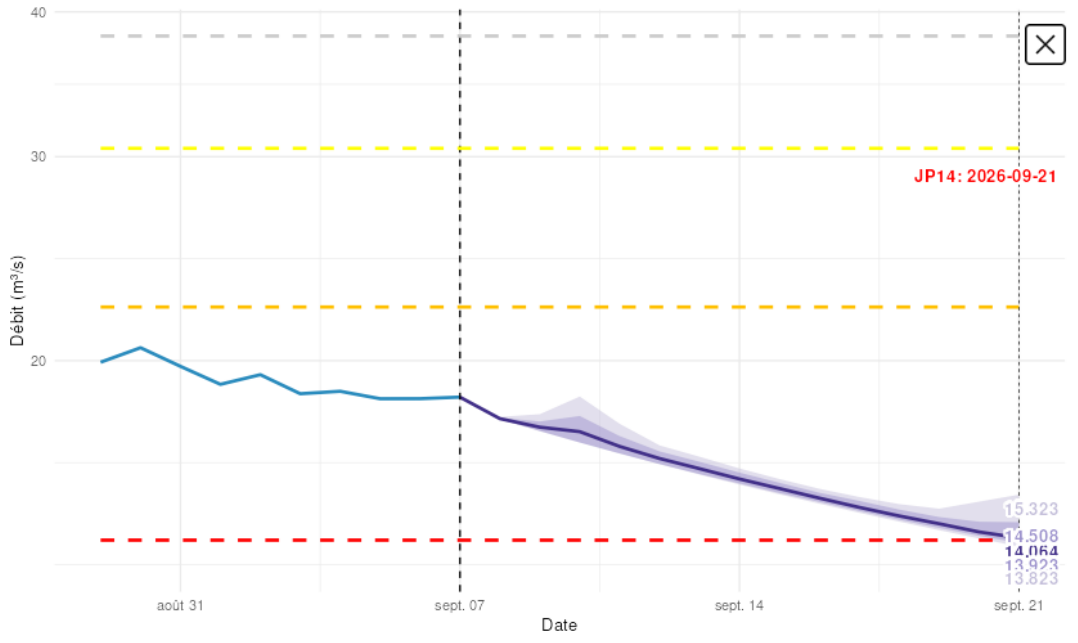
Increasing drought risk



Number of days of restrictions per year related to drought between January 1, 2013 and August 31, 2026 for the Meuse département

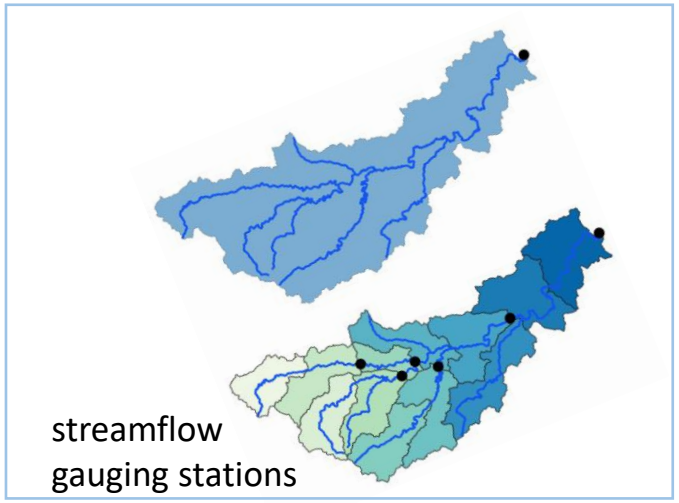
Source : https://www.estrepublicain.fr/environnement/2026/09/02/ete-2026-en-lorraine-quatre-graphiques-pour-visualiser-l-ampleur-de-cette-secheresse-exceptionnelle

→ need for accurate low-flow forecasting : **CIPRHES** [1, 5]: French research project on low-flow simulation and forecasting



14-Day Daily Streamflow Forecast for the Meuse River at Chooz - ECMWF Forcing, Issue date : 07/09/2026 (PREMHYCE platform)

Context and Objectives



Difference between lumped and semi-distributed models

- **Lumped model**:
  - single hydrological unit,
  - average climatic inputs,
  - spatially uniform model parameters

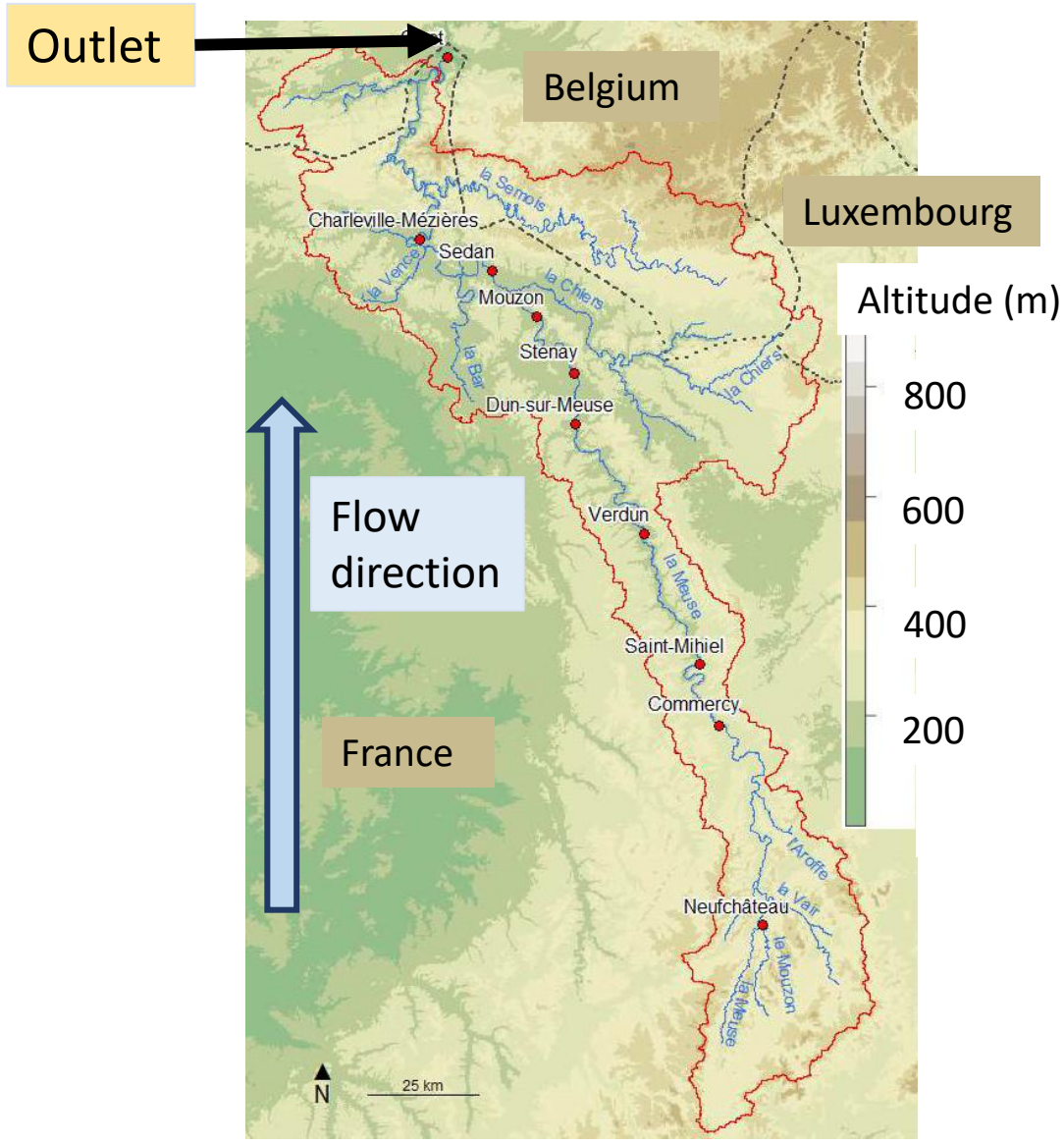
- **Semi-distributed model**:
  - several hydrological units,
  - explicitely accounts for some spatial physical and climatic variability,
  - possibility of using several parameter sets

Comparison of 4 semi-distributed hydrological models on the same study catchment

- What are the strengths and limitations for low-flow simulation?

Methods: Study area

- **French Meuse catchment, 10,140 km²**
- Flowing from South to North
- Low population density, limited human influence
- **Strong geographical contrasts**:
  - *Upstream*: long corridor, plateau relief, sedimentary formation, cropland and grassland
  - *Downstream*: Ardennes massif, old and highly eroded, mainly composed of schist, predominantly forest landscape
- Presence of karstified areas upstream

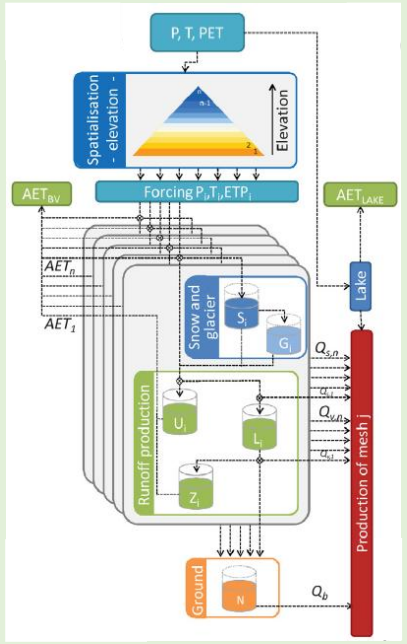


French Meuse catchment [7]

Methods: Semi-distributed hydrological models

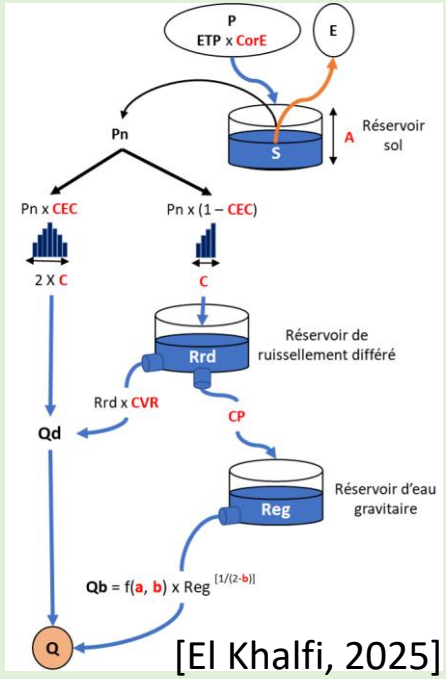
- **4 conceptual hydrological models** with different formulations / options.

MORDOR-TS



[Rouhier et al., 2017]

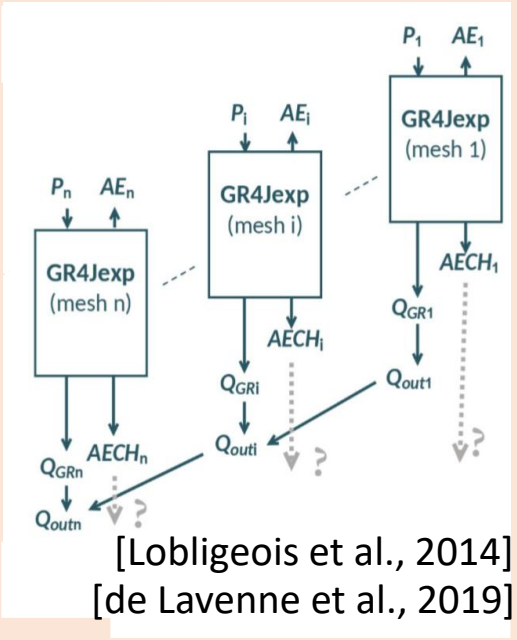
PRESAGES



[El Khalfi, 2025]

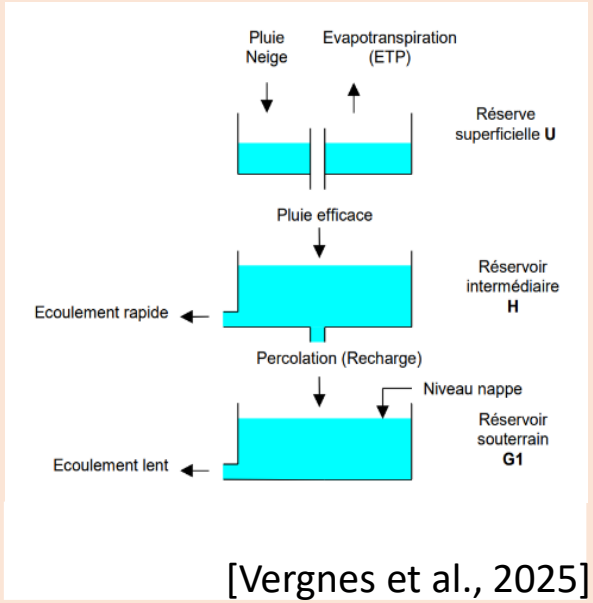
No intercatchment groundwater flows

GRSD



[Lobligeois et al., 2014]
[de Lavenne et al., 2019]

RAMEAU



[Vergnes et al., 2025]

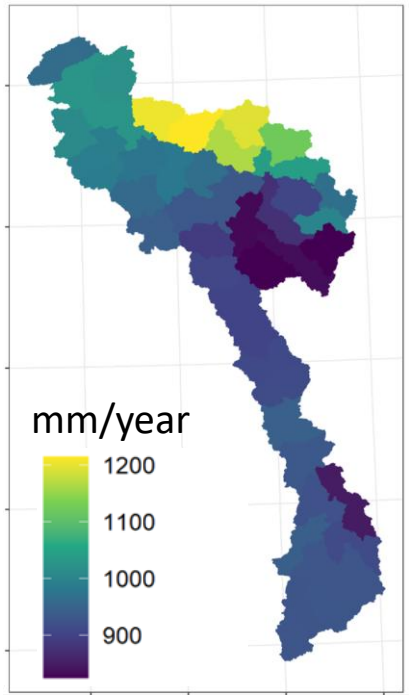
Possibility of intercatchment groundwater flows (IGF*)

*definition in appendix

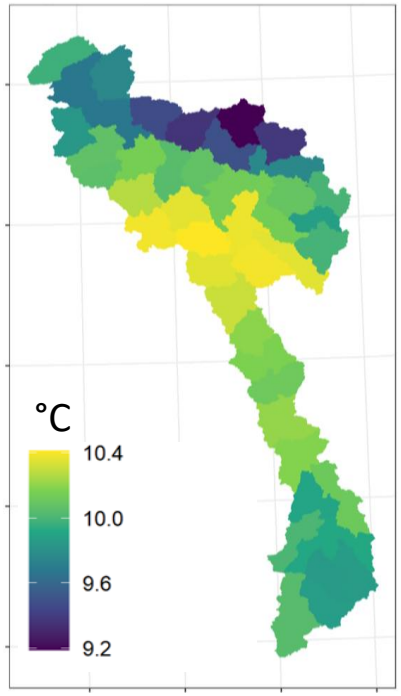
Methods: Data and Calibration

- **Harmonised calibration strategy** using data from 2000-2022.

Average precipitation



Average temperature



+ PET from Penman-Monteith

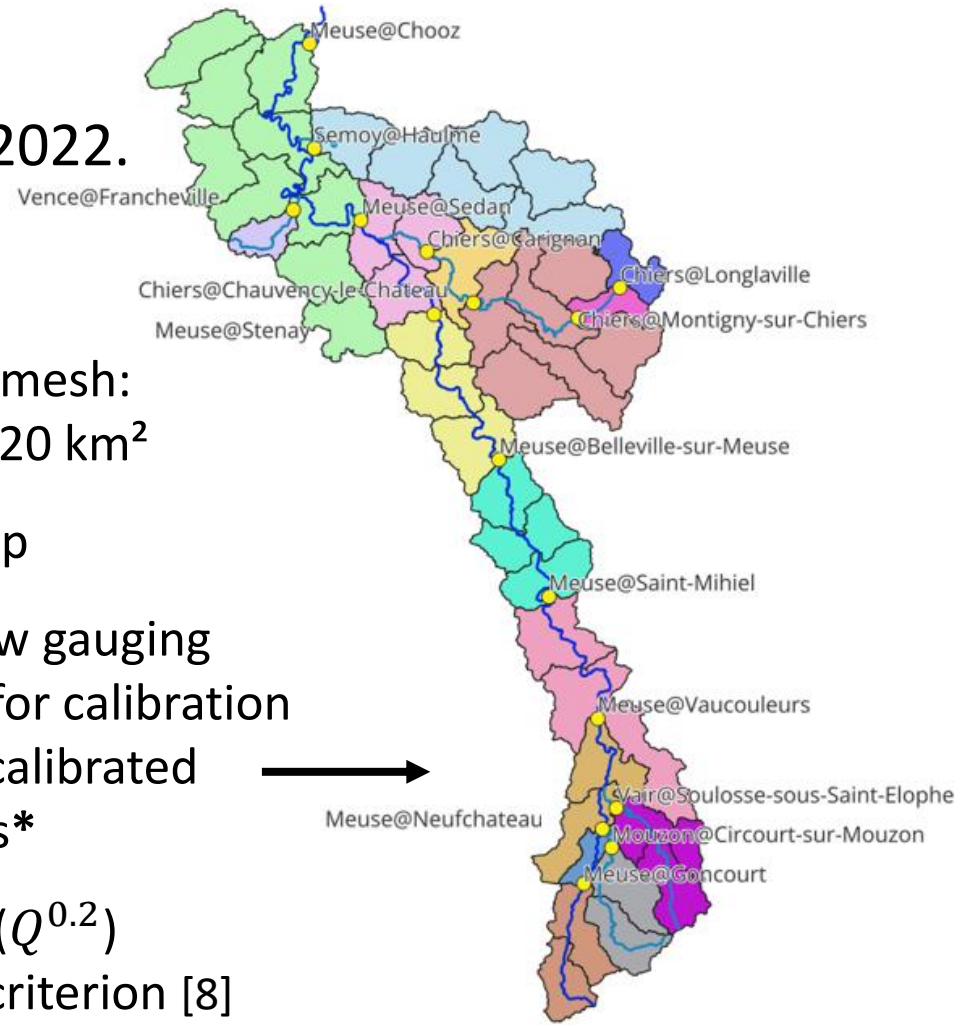
Meteorological input data (SAFRAN reanalyses [7])

- Hydrological mesh:
46 units of ~ 220 km²

- Daily timestep

- 16 streamflow gauging stations used for calibration
→ 16 sets of calibrated parameters*

- Use of a KGE($Q^{0.2}$) performance criterion [8]

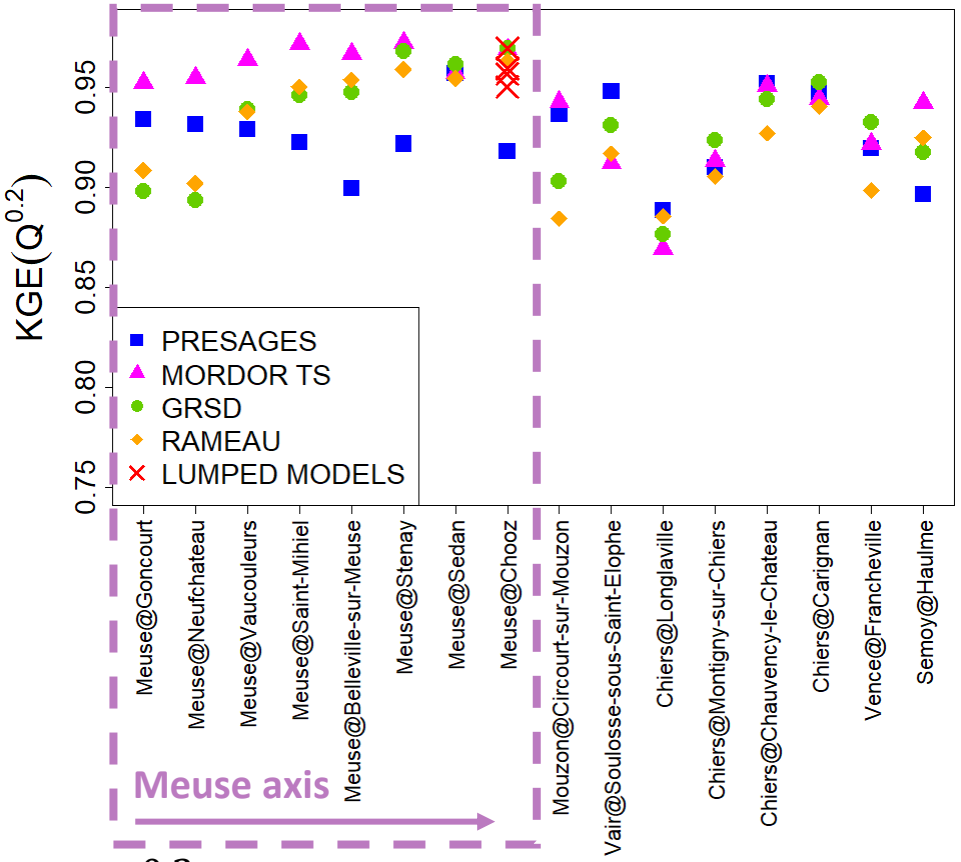


Calibration patterns and gauging stations (8 on the Meuse axis)

*except for PRESAGES (46 sets)

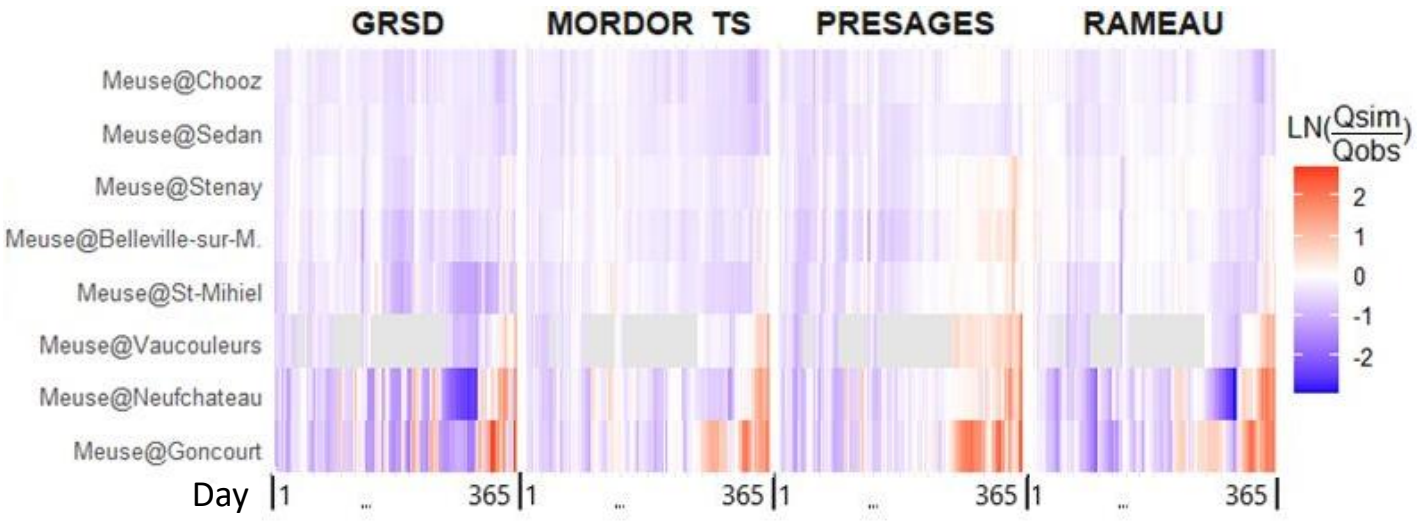
Results: Model performances

- KGE($Q^{0.2}$) values are satisfying and similar to lumped models at the outlet.



KGE($Q^{0.2}$) performance criteria for the 16 stations

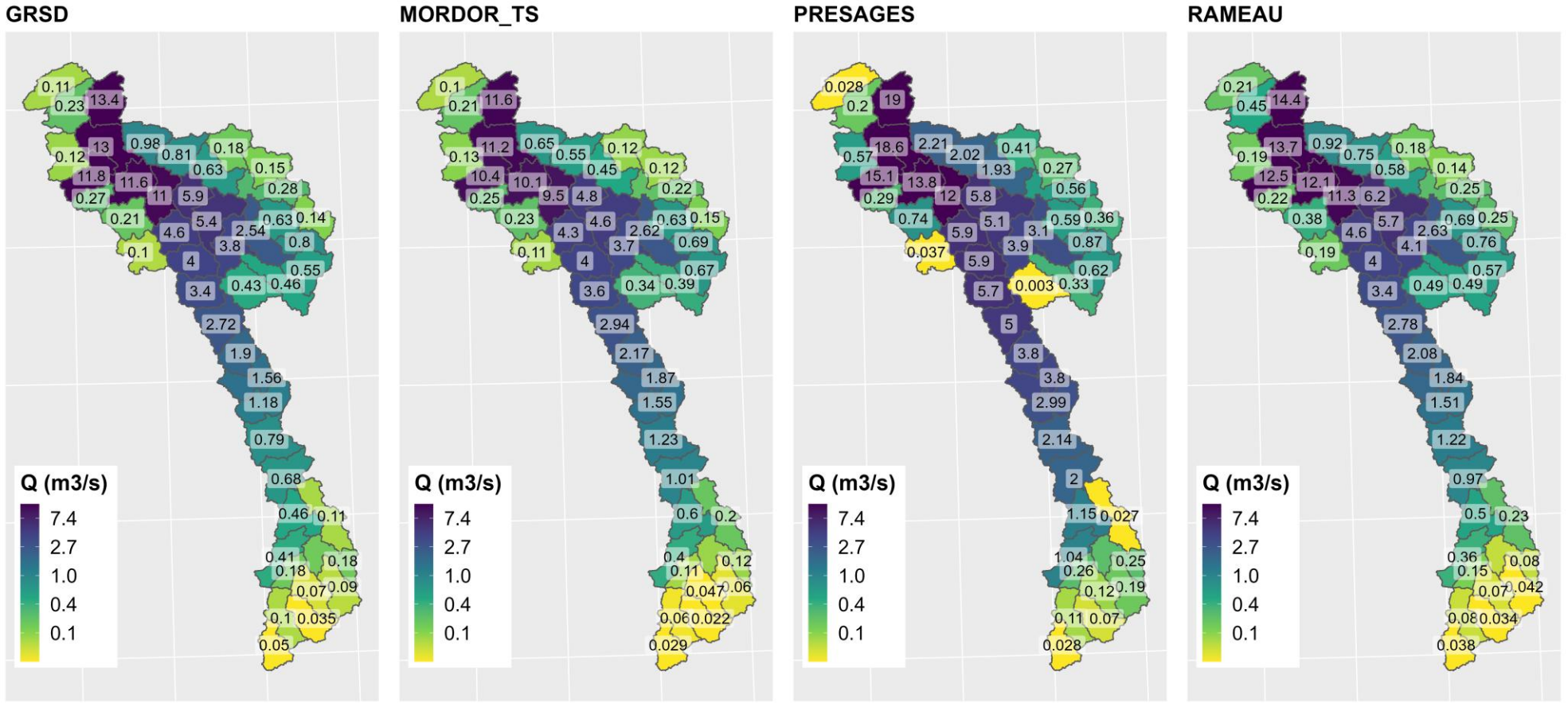
- Similar signs of bias among the models, possibly reflecting **common structural limitations** or **uncertainties** in low-flow measurements and meteorological data.



Logarithmic ratios relative to observed streamflows along the Meuse axis (year 2022)

Results: Representation of low flows

- The models provide consistent **low-flow estimation at gauged and ungauged locations.**

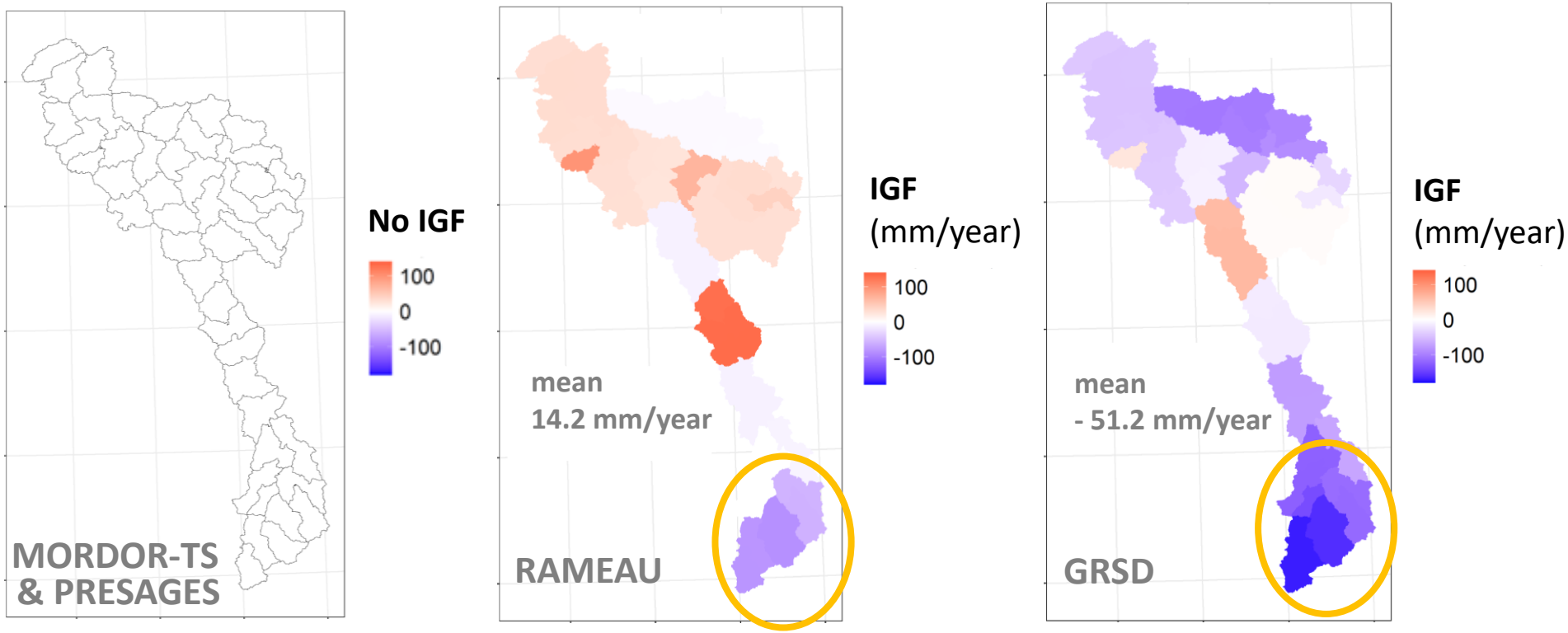


Simulated mean flow for August 2022

Results: Intercatchment Groundwater Flows (IGF)

- The models show substantial differences in their representations of **IGF.**
- **Future research** should focus on improving groundwater flows understanding and representation within hydrological models.

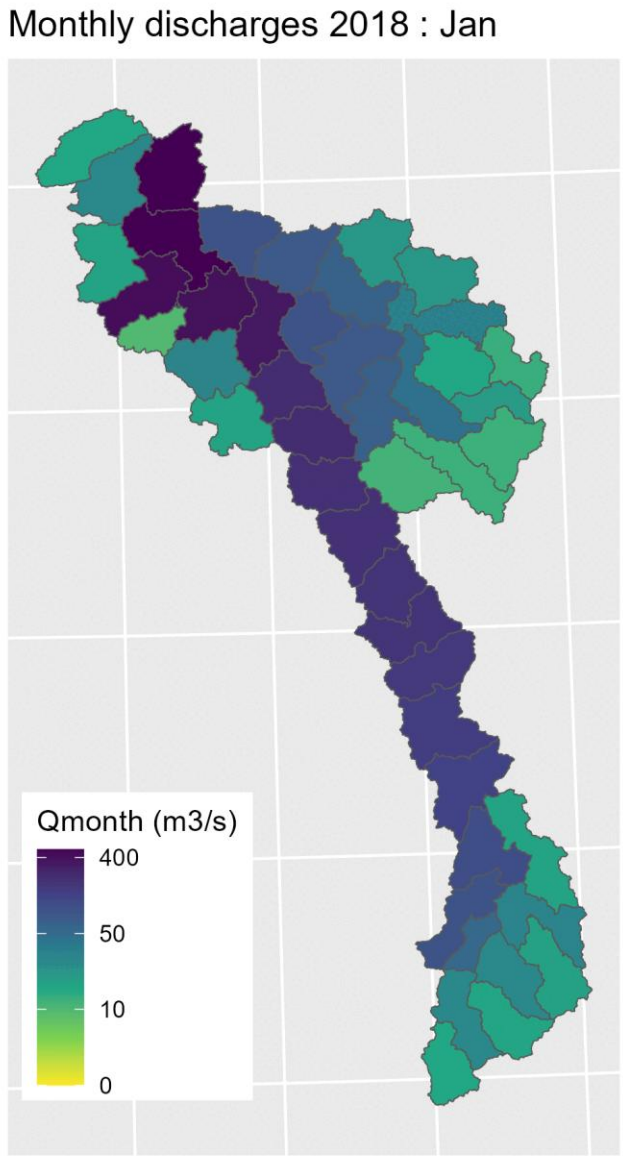
Water balance:
$Q = P - AE + IGF - \Delta S$



Mean annual IGF for three types of models: no IGF and two models with IGF formulations

Conclusion and Perspectives

- **Four semi-distributed models** were implemented in a catchment with strong geographical contrasts.
- Following a joint calibration exercise, the models provide **consistent results** across the catchment and **low-flow estimation at gauged and ungauged locations**.
- **Similar signs of bias** were observed among the models, which may reflect **common structural limitations** or **uncertainties** in flow measurements and meteorological data.
- Future research should focus on improving the understanding of **groundwater flows** and their representation within hydrological models.



Thank you for listening!

Hajar El Khalfi[1], Camille Brun[2], Alban de Lavenne[3], Claire Delus[1], Didier François[1], Thibault Hallouin[4], Frédéric Hendrickx[2], Shu-Chen Hsu[3], Céline Monteil[2], Jean-Pierre Vergnes[4]

1 - Université de Lorraine, LOTERR, Metz, France ✉ hajar.el-khalfi@univ-lorraine.fr

2 - EDF R&D, LNHE, Chatou, France ✉ camille.brun@edf.fr

3 - INRAE, HYCAR, Antony, France ✉ alban.delavenne@inrae.fr

4 - BRGM, Orléans, France ✉ t.hallouin@brgm.fr

The CIPRHES project is funded by the French National Research Agency (grant ANR-20-CE04-0009-03).

References:

[1] Brun, C., de Lavenne, A., Delus, C., El Khalfi, H., François, D., et al. - **Vers une modélisation semi-distribuée pour la simulation des étiages : comparaison de quatre modèles hydrologiques sur le bassin de la Meuse française**. EDF R&D; INRAE; Université de Lorraine; BRGM. 2026. ⟨hal-05534380⟩

[2] de Lavenne, A., Andréassian, V., Thirel, G., Ramos, M.-H., Perrin, C. (2019). - **A Regularization Approach to Improve the Sequential Calibration of a Semi-distributed Hydrological Model.** Water Resources Research 55. https://doi.org/10.1029/2018WR024266.

[3] El Khalfi, H. (2025). - **Modélisation des étiages et des tarissements dans le bassin de la Moselle : d'une approche globale à une approche spatialisée**, Thèse de doctorat, Université de Lorraine, https://hal.univ-lorraine.fr/THESES-UL/tel-05128870.

[4] Lobligeois F., Andréassian V., Perrin C., Tabary P., Loumagne C. (2014). - **When does higher spatial resolution rainfall information improve streamflow simulation? An evaluation using 3620 flood events.** Hydrol. Earth Syst. Sci. 18, 575–594. https://doi.org/10.5194/hess-18-575-2014.

[5] Perrin, C., Andréassian, V., Batté, L., Bernard, P., Bessiere, H., et al. - **Chaine intégrée pour la prévision hydrométéorologique des étiages et des sécheresses - Rapport final du projet CIPRHES.** Université Paris-Saclay, INRAE, UR HYCAR, Antony; Météo-France, DCSC, Toulouse; EDF - DTG, Saint-Martin-le-Vinoux; BRGM, Orléans; LOTERR, Université de Lorraine, Metz; EDF, LHNE, Chatou; Météo-France, CNRS, CNRM, Toulouse; INRAE, UR RIVERLY, Lyon-Villeurbanne; Office français de la biodiversité (OFB), Direction de la recherche et de l'appui scientifique, Vincennes; Ministère de la Transition écologique, Direction de l'eau et de la biodiversité, La Défense. 2026, pp.39. ⟨hal-05559493⟩

[6] Rouhier L., Le Lay M., Garavaglia F., Le Moine N., Hendrickx F., Monteil C., Ribstein P. (2017). - **Impact of mesoscale spatial variability of climatic inputs and parameters on the hydrological response**, Journal of Hydrology, 553: 13–25, http://dx.doi.org/10.1016/j.jhydrol.2017.07.037.

[7] Thirel G., Collet L., Rousset F., Delaigue O., François D., Gailhard J., Le Lay M., Perrin C., Reverdy M., Samacoits R., Terrier M., Vidal J.-P., Wagner J.-P. (2021). **- Projet CHIMERE 21. CHIers - Meuse : Evolution du RégimE hydrologique au 21e siècle**. Rapport final. hal-03206168.

[8] Thirel G., Santos L., Delaigue O., Perrin C. (2023). - **On the use of streamflow transformations for hydrological model calibration**. 10.5194/egusphere-2023-775.

[9] Vergnes, J.-P., Hallouin, T. (2025). - **Rameau: a software dedicated to the modelling of river flows and/or groundwater levels in watersheds of various scales (v0.0.7)**. Zenodo. https://doi.org/10.5281/zenodo.15420338.

Appendix

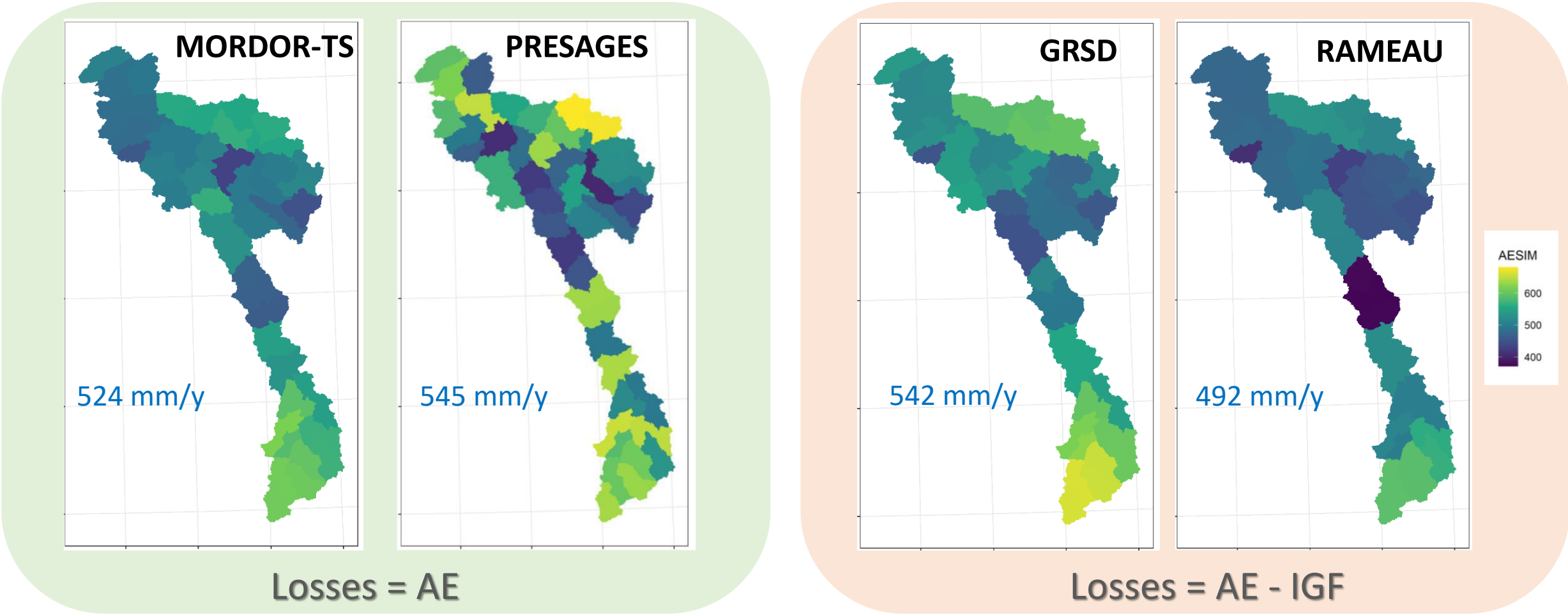
Intercatchment Groundwater Flow (IGF) definition :

''IGF is understood as either the water lost by the catchment to regional aquifers, i.e. part of the catchment rainfall that will feed underground aquifers that do not contribute to the surface flow at the catchment outlet, or the water coming from outside the topographic catchment boundaries, e.g. due to geological structures connecting the catchment with surrounding catchments that will contribute to the surface flow.'' [10]

[10] Hsu, S. C., de Lavenne, A., Perrin, C., Andréassian, V. (2025). - Extra constraint on actual evaporation in a semi-distributed conceptual model to improve model physical realism. Hydrological Sciences Journal, 70(7), 1143–1156. https://doi.org/10.1080/02626667.2025.2468846.

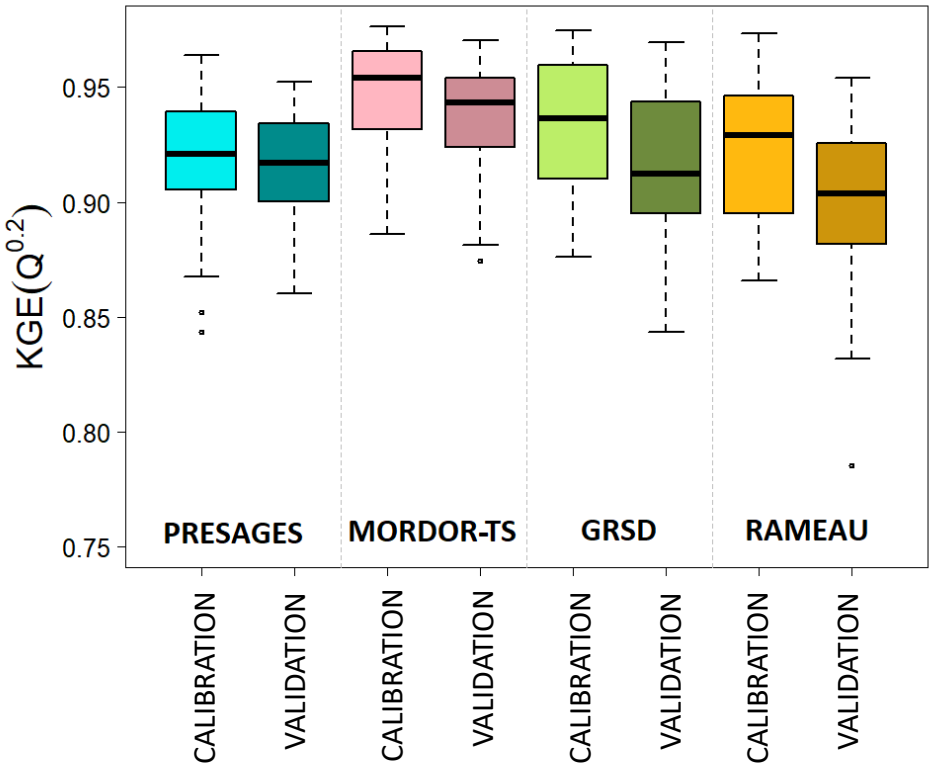
Appendix : Water balance

- *Representation of losses (to the atmosphere and to groundwater): Q = P – losses*

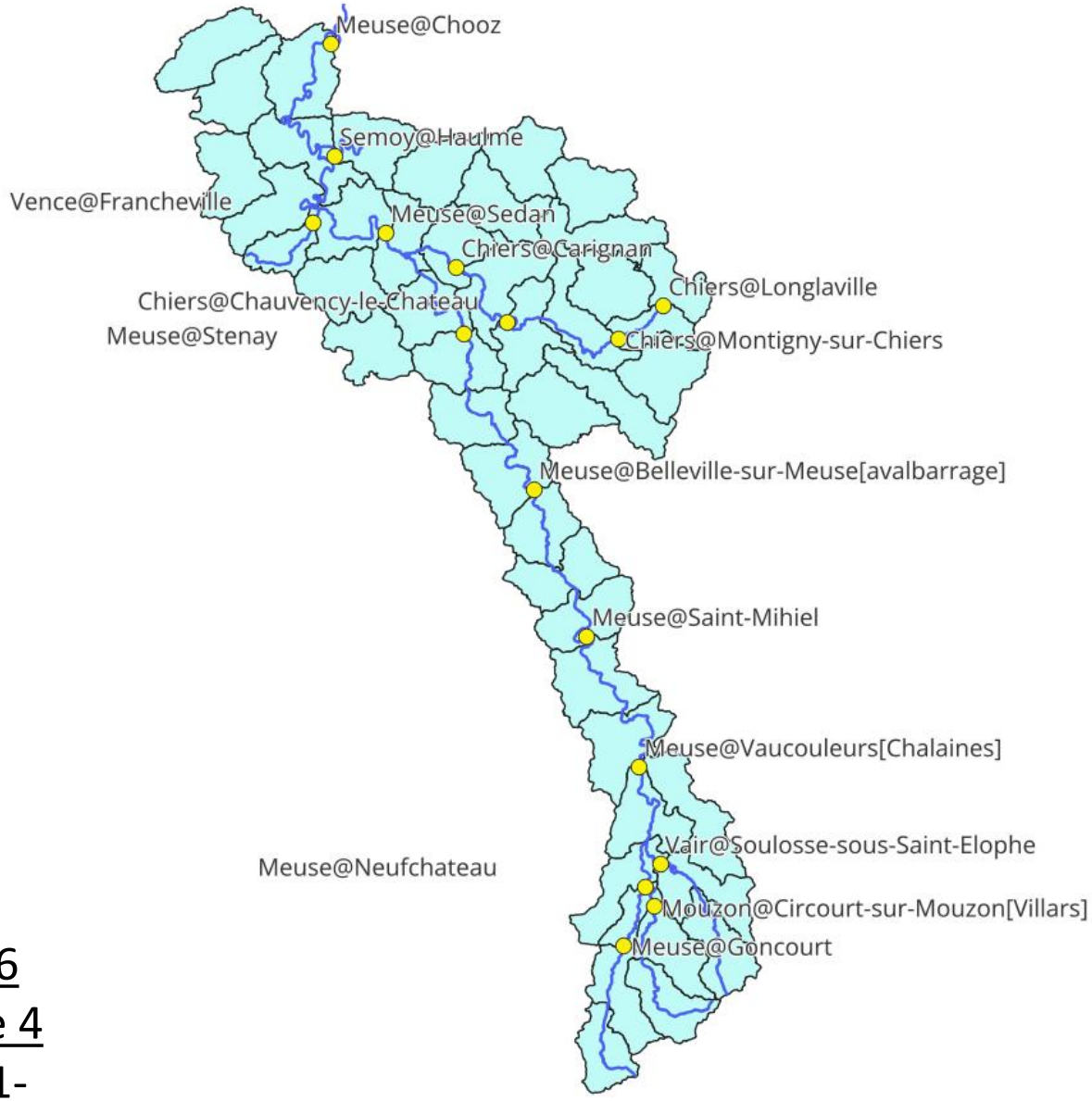


Simulated mean annual losses between 2000 and 2022 (mm/year)

Appendix

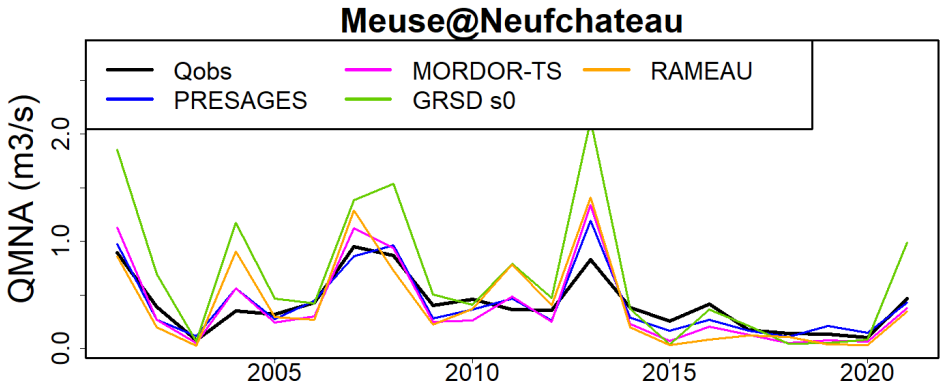


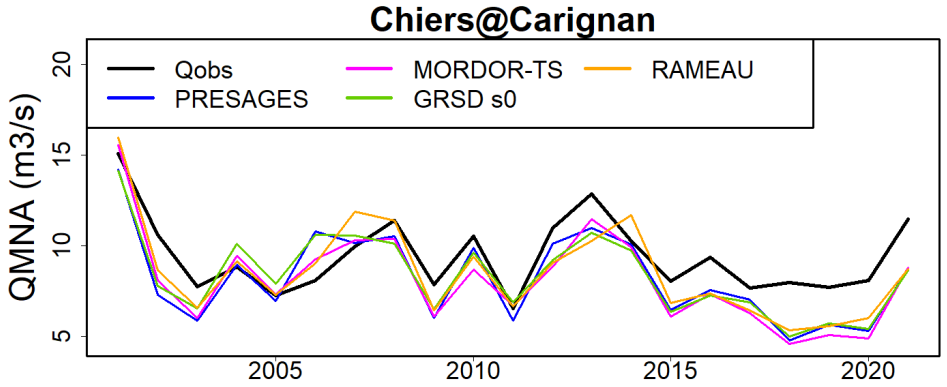
Statistical distributions of KGE($Q^{0.2}$) across the 16 stations for calibration and validation periods. The 4 models were calibrated over 2000-2011 and 2011-2022 and validated on the complementary periods.



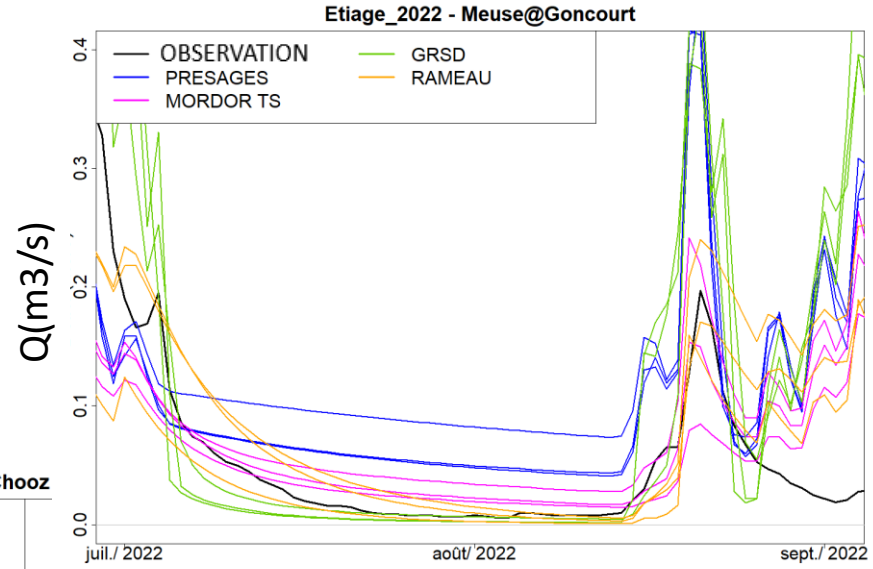
The 16 streamflow gauging stations

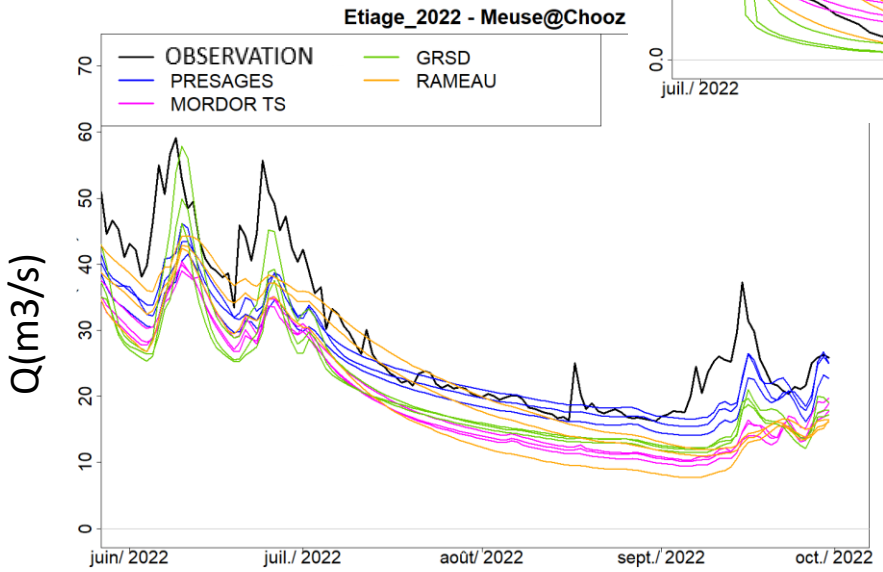
Appendix





Example of observed and simulated annual minimum monthly streamflow (QMNA) at two stations for models calibrated over 2000-2022





Example of observed and simulated 2022 low-flow conditions at two stations. For each model, the three curves correspond to three calibration periods (2000-2011, 2011-2022, 2000-2022)