

Explore2 - The future of water in France

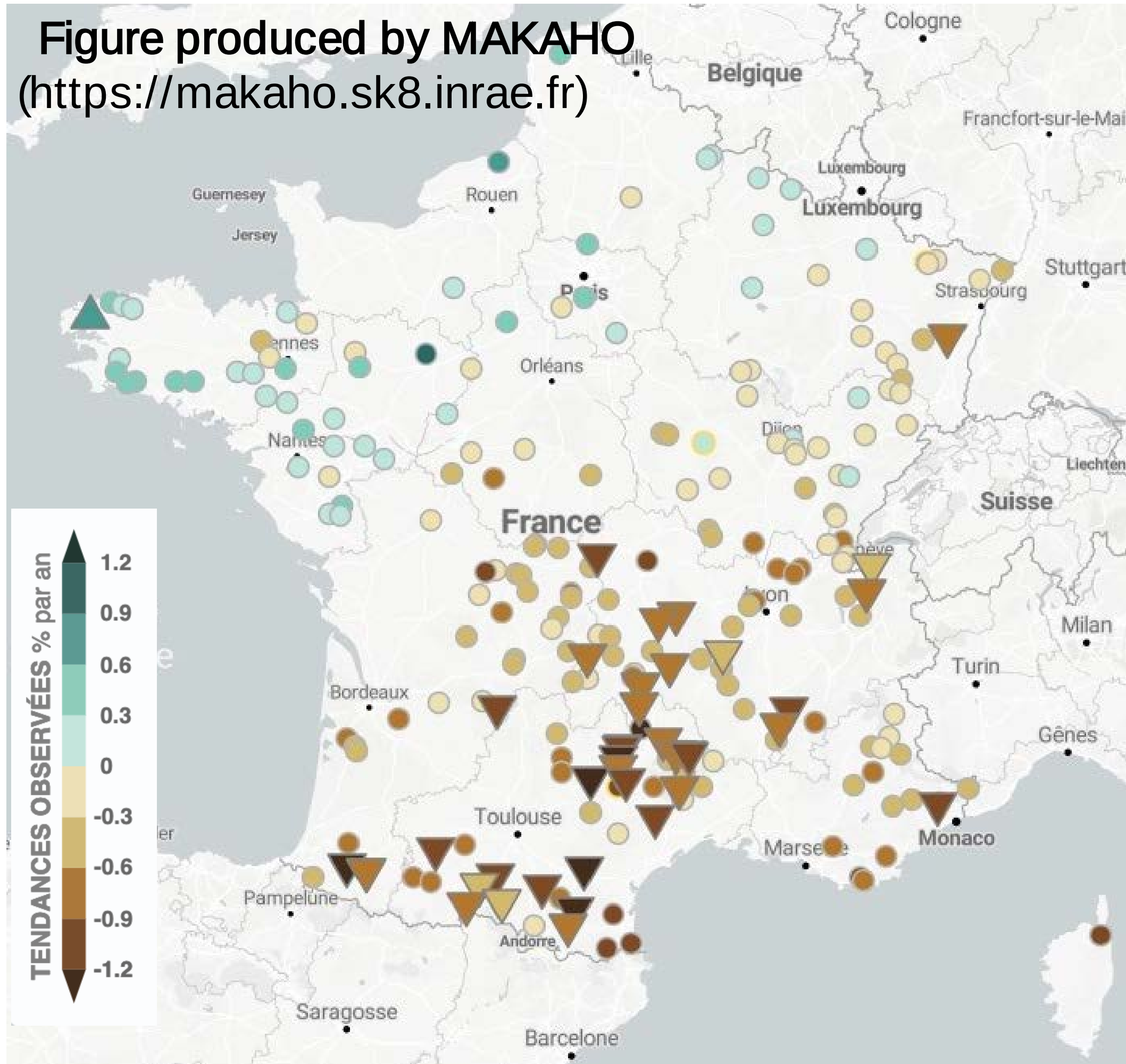
Project overview and contributions from IPSL

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The Explore2 project: context and objectives

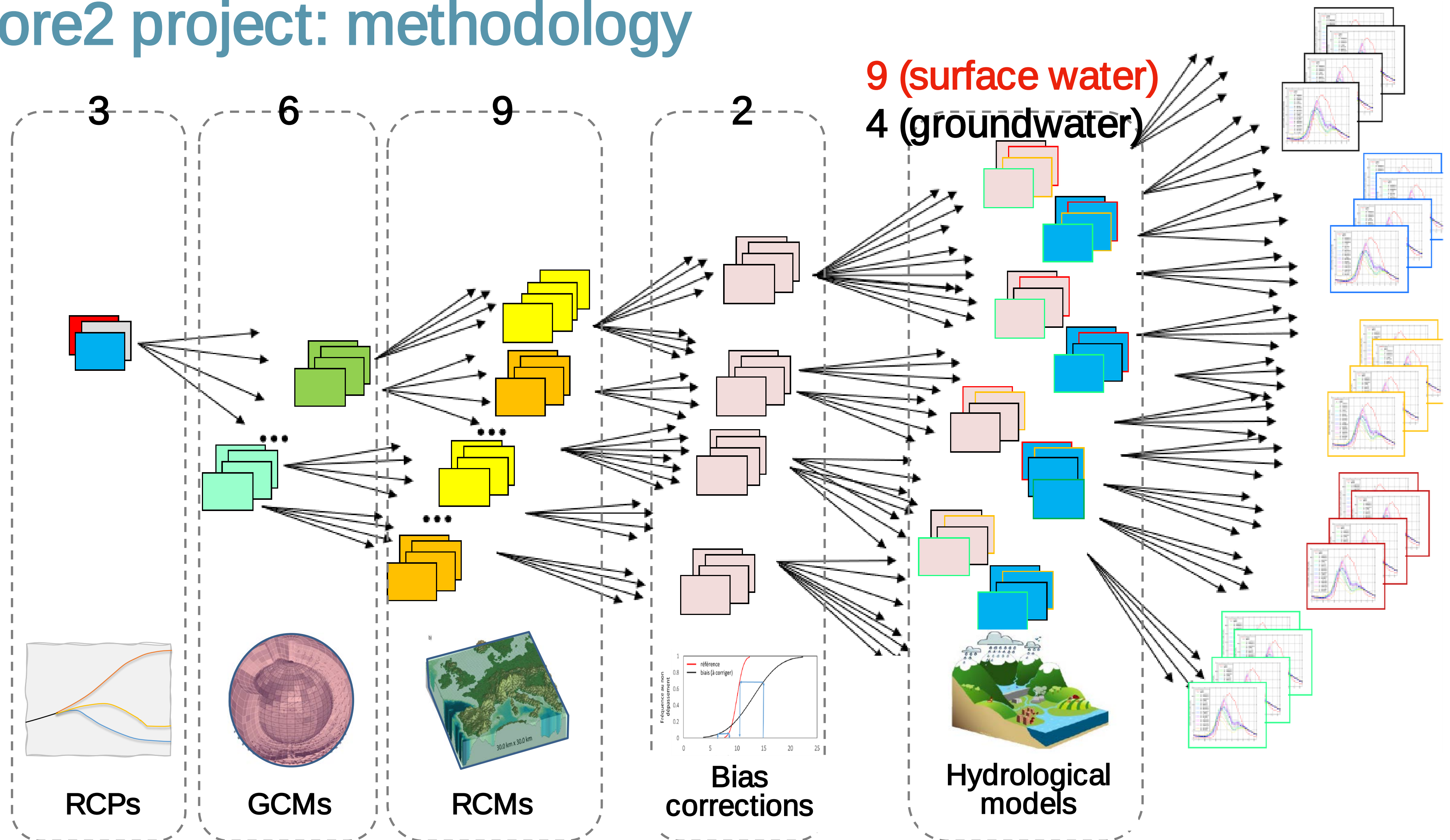


Observed annual Q trend for “natural” basins
in France over the period of 1968-2024

- **A French national project** (2021-2024), led by **INRAE** (French National Research Institute for Agriculture, Food, and Environment) and **OiEau** (International Office for Water), co-financed by **OFB** (French Biodiversity Agency) and **MTECT** (French Ministry of Ecological Transition)
- **Objectives**
 1. **Scientific part:** to update the understanding on the hydrological impact of climate change in France for the 21st century
 2. **Knowledge transfer:** to support French water managers and stakeholders to adapt their water resource management strategies

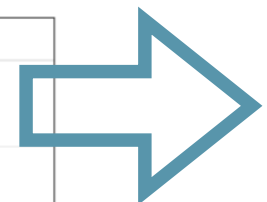
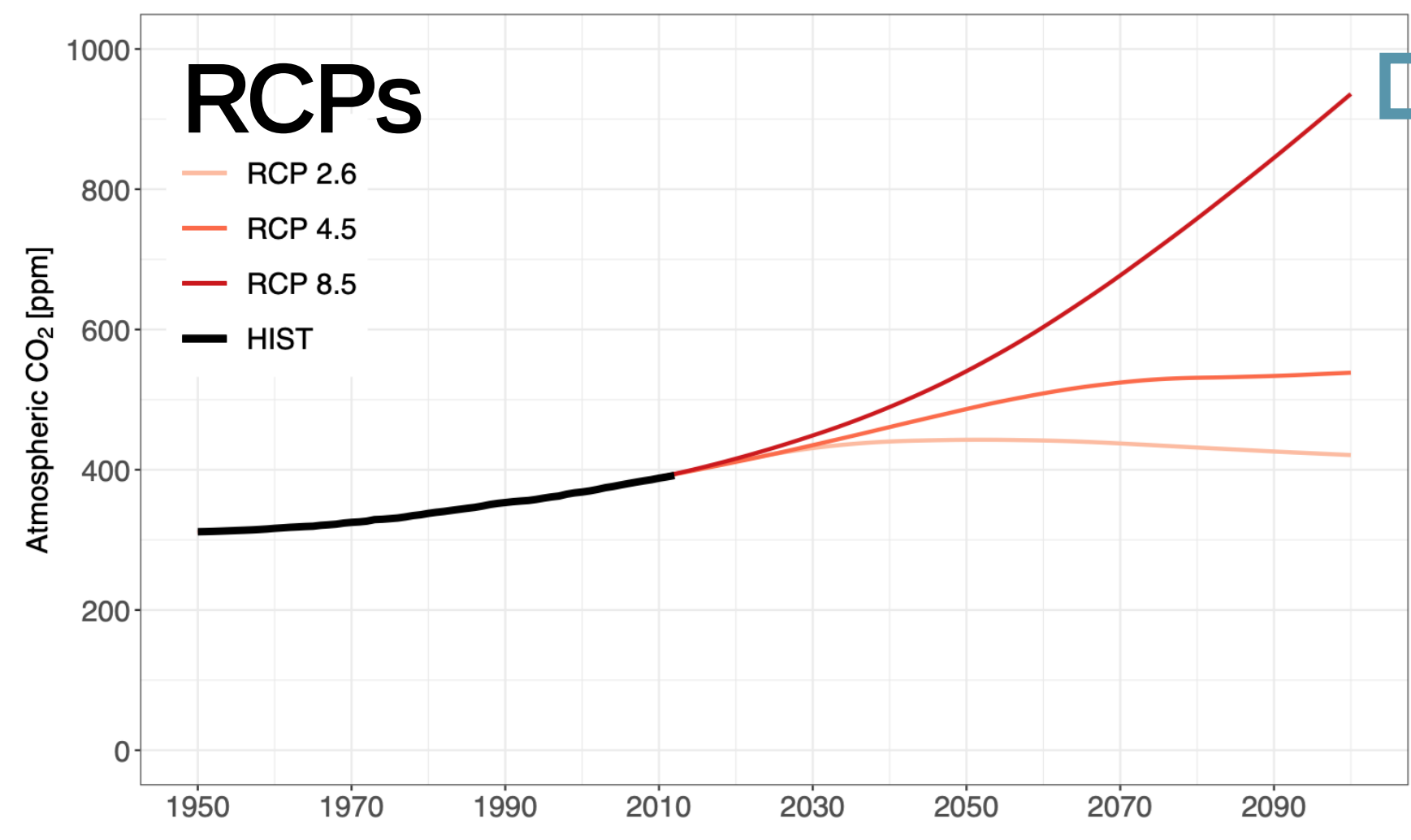


The Explore2 project: methodology



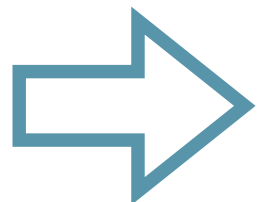
A top-down modelling chain with multiple scenarios and multiple models
to project future water resources

The Explore2 project: methodology



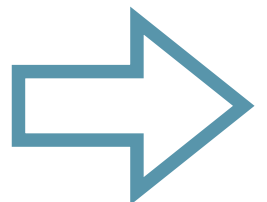
GCMs

1. CNRM-CM5-LR
2. EC-Earth
3. HadGEM2-ES
4. IPSL-CM5A-MR
5. MPI-ESM-LR
6. NorESM1-M



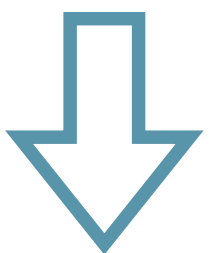
RCMs

1. ALADIN63
2. CCLM4-8-17
3. HadREM3-GA7-05
4. HIRHAM5
5. RACMO22E
6. RCA4
7. RegCM4-6
8. REMO
9. WRF381P



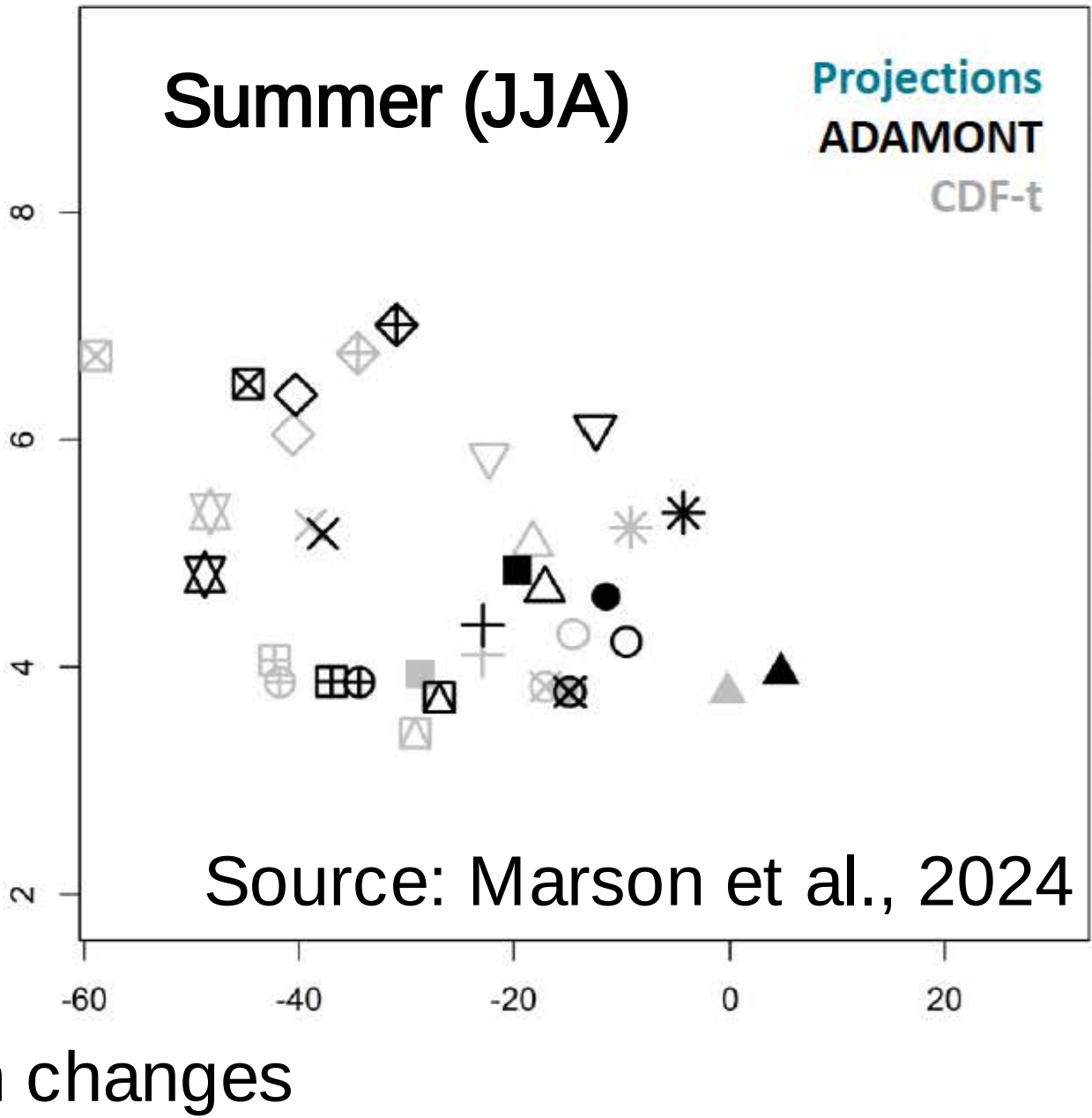
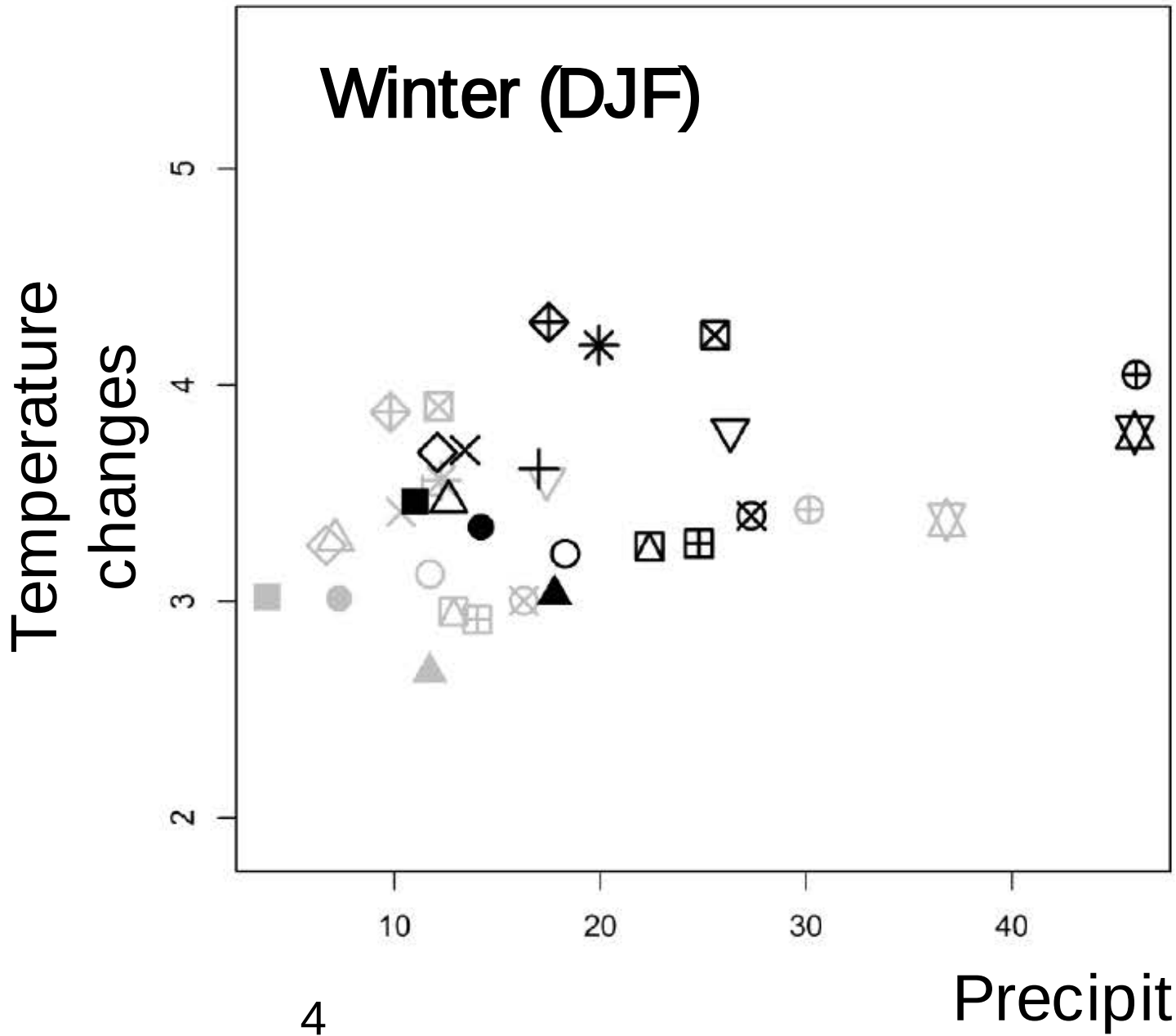
BCMs

1. ADAMONT (hourly)
2. CDFt (daily)

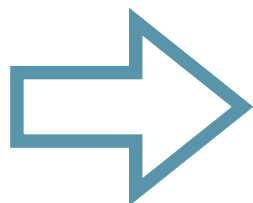


**72 climate projections
for France**

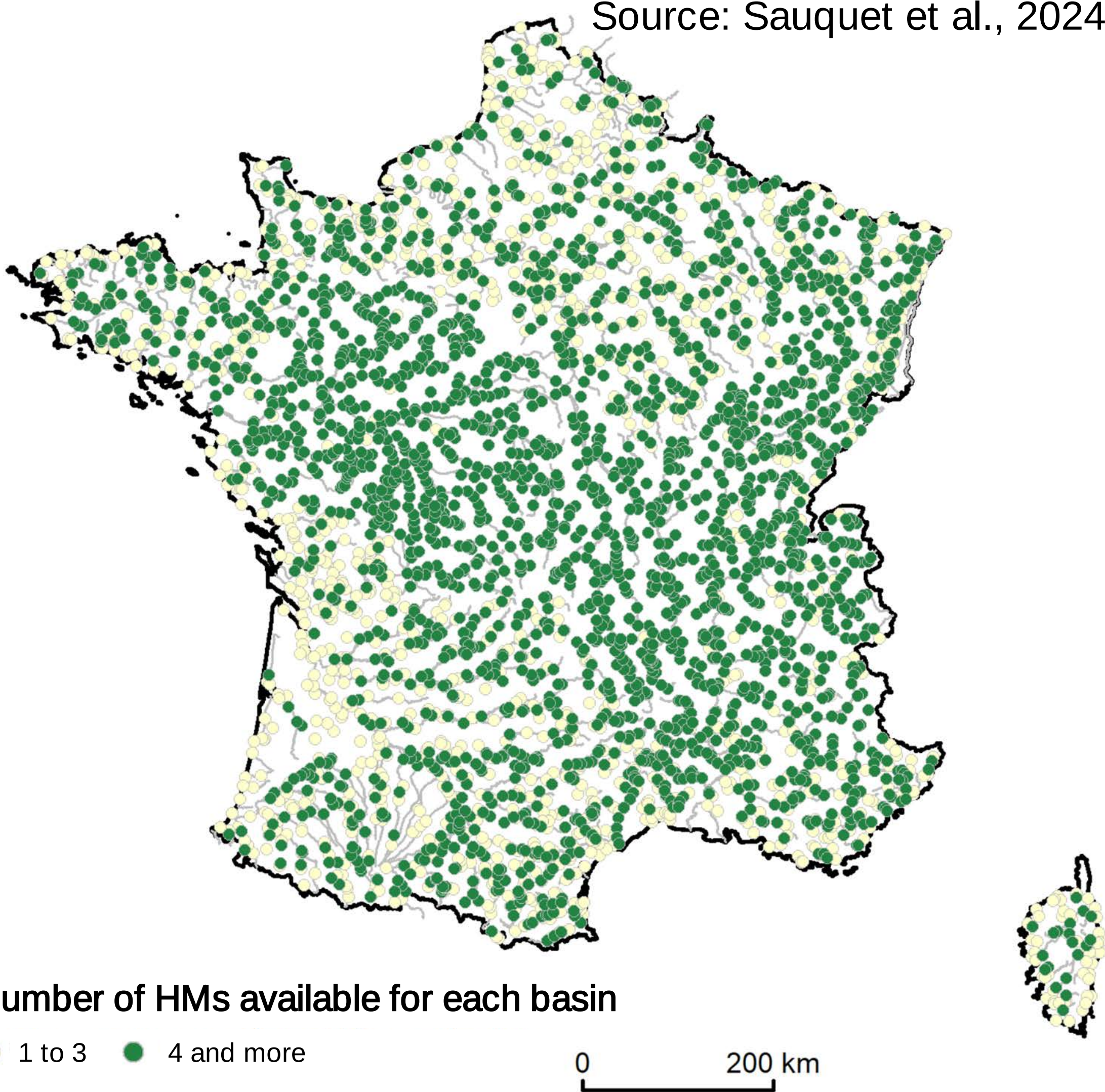
Precipitation and temperature changes
over France under RCP 8.5
of 2070-2099 compared to 1976-2005



The Explore2 project: methodology



9 HMs for surface water	Simulated area	Simulated basins
CTRIP (Decharme et al., 2019)	France	2024
EROS (Seyedhashemi et al., 2022)	Brittany, Loire	387
GRSD (de Lavenne et al., 2019)	France	3712
J2000 (Krause et al., 2006)	Loire, Rhône	1291
MORDOR-SD (Garavaglia et al. 2017)	France	611
MORDOR-TS (Rouhier, 2018)	Loire	535
ORCHIDEE (Huang et al., 2024)	France	3587
SIM2 (Le Moigne et al., 2020)	France	649
SMASH (Jay-Allemand et al., 2020)	France	3821



The Explore2 project has produced a large ensemble of hydrological projections for around 4000 river basins in France

The Explore2 project: outputs

Knowledge transfer

- **Dataverse** for summary reports on the main messages of the Explore2 project (<https://entrepot.recherche.data.gouv.fr/dataverse/explore2>)
- **MOOC** for online trainings on understanding hydroclimatic projections designed for water managers and stakeholders (<https://e-learning.oieau.fr/enrol/index.php?id=3799>)

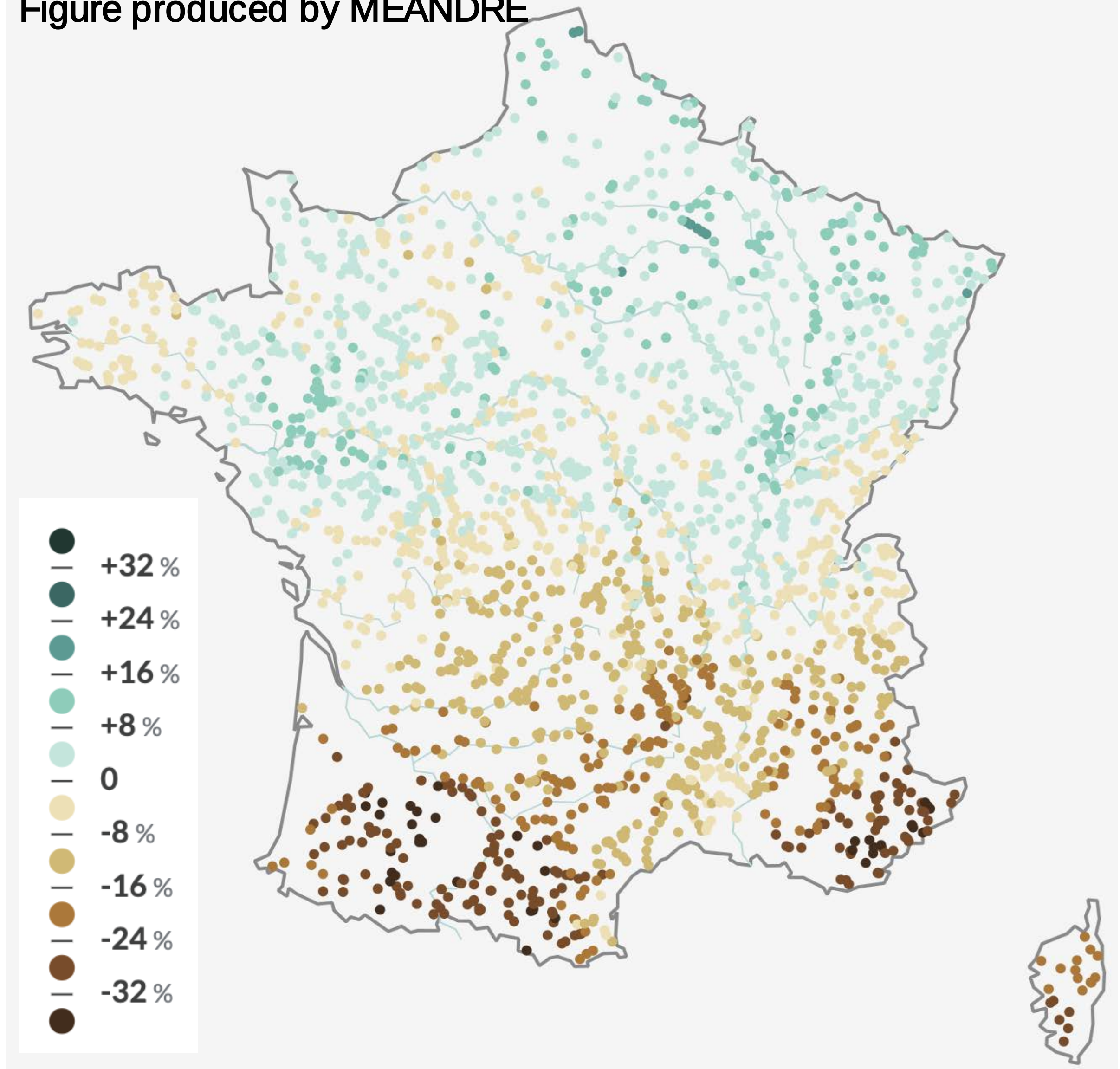
Data available for download

- **Le Portail DRIAS-Climat** for climate projections (<https://www.drias-climat.fr>)
- **Le Portail DRIAS-EAU** for hydrological projections (<https://www.drias-eau.fr>)

Data visualization

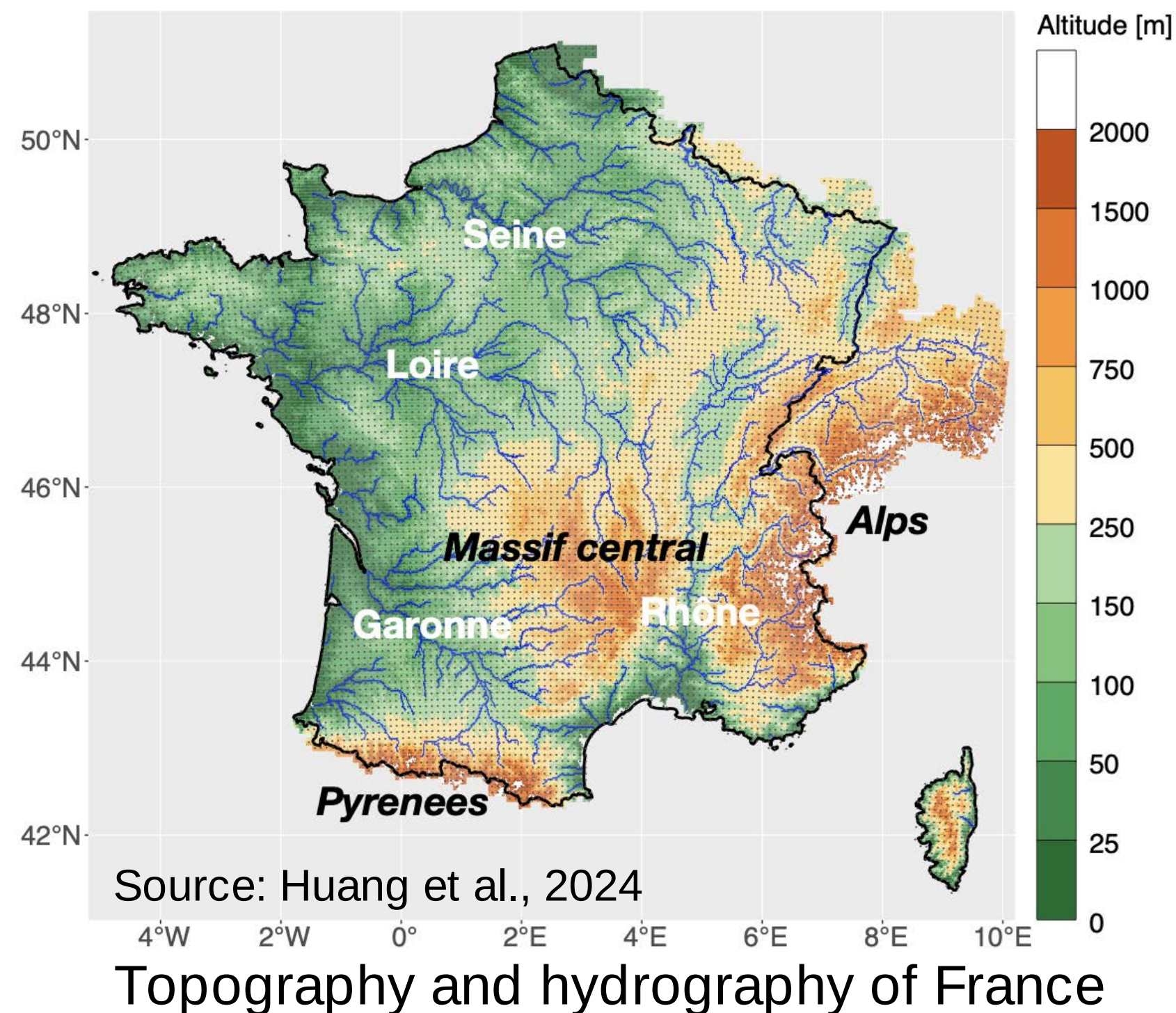
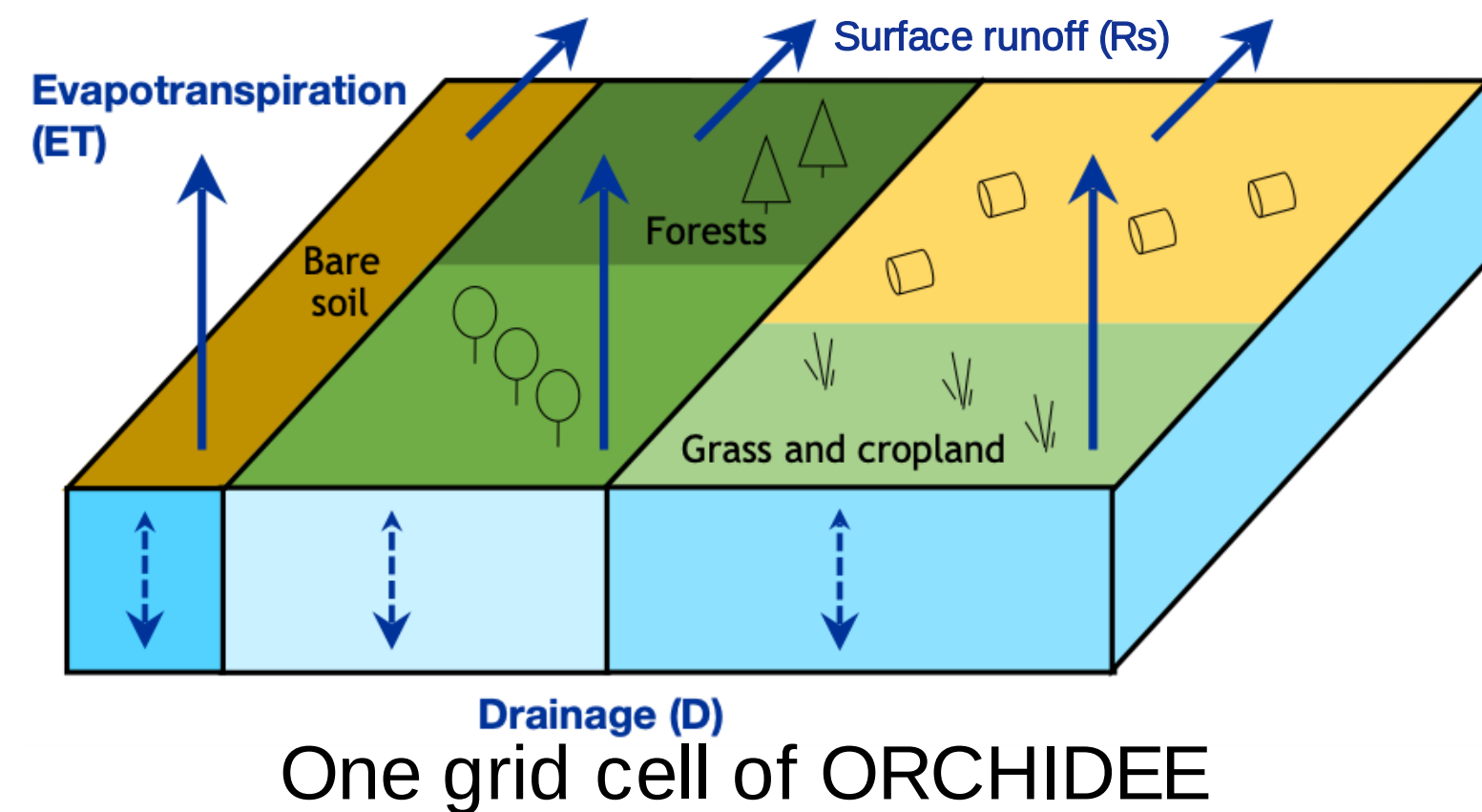
- **MAKAHO** for visualizing the observed hydrological records in France (<https://makaho.sk8.inrae.fr>)
- **MEANDRE** for visualizing the hydrological projection results in France (<https://meandre.explore2.inrae.fr>)

Figure produced by MEANDRE



Annual Q changes under RCP 8.5 (ADAMONT and CDFt)
of 2070-2099 compared to 1976-2005
for basins simulated by at least 4 HMs

Contributions from IPSL: ORCHIDEE configuration

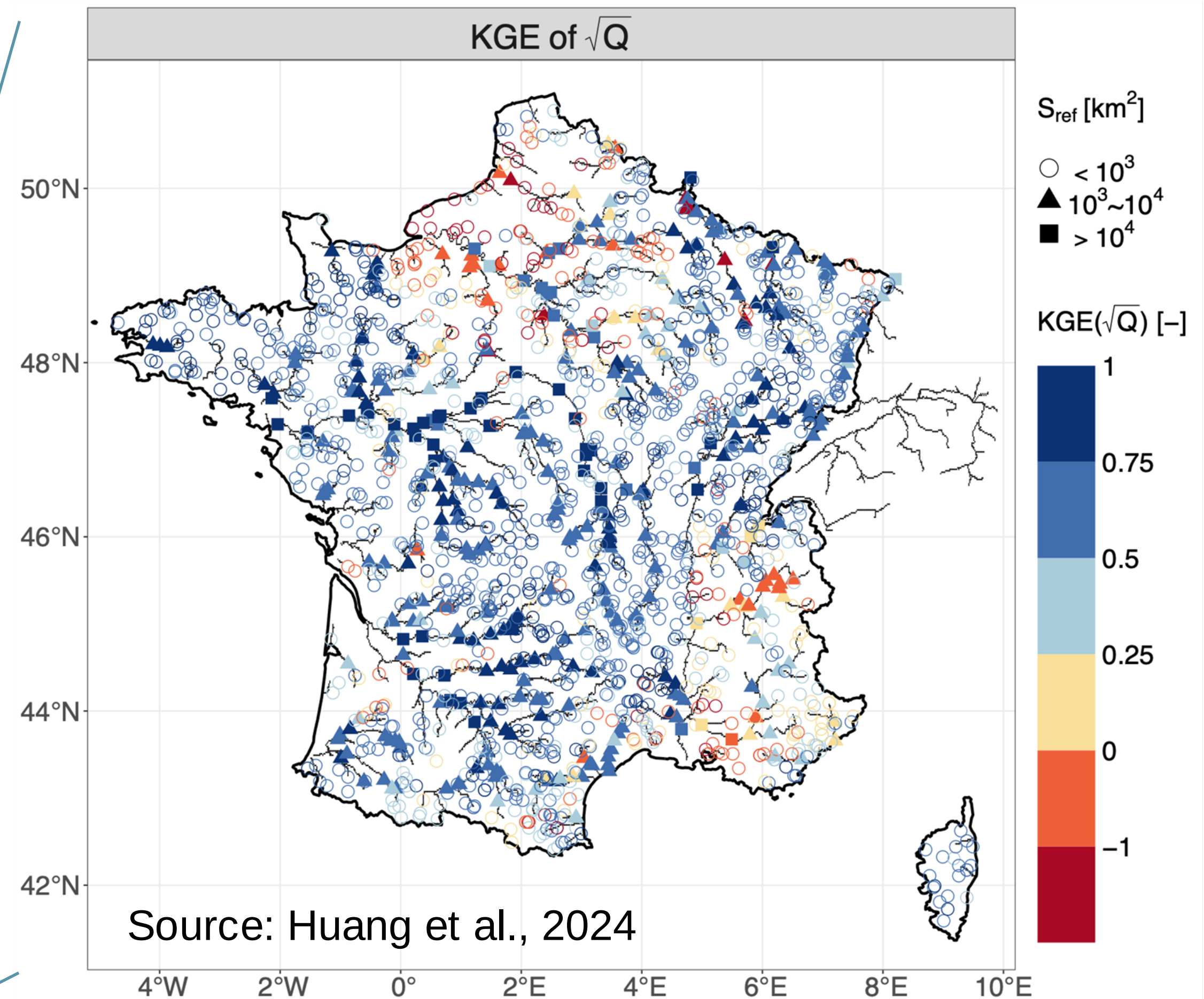
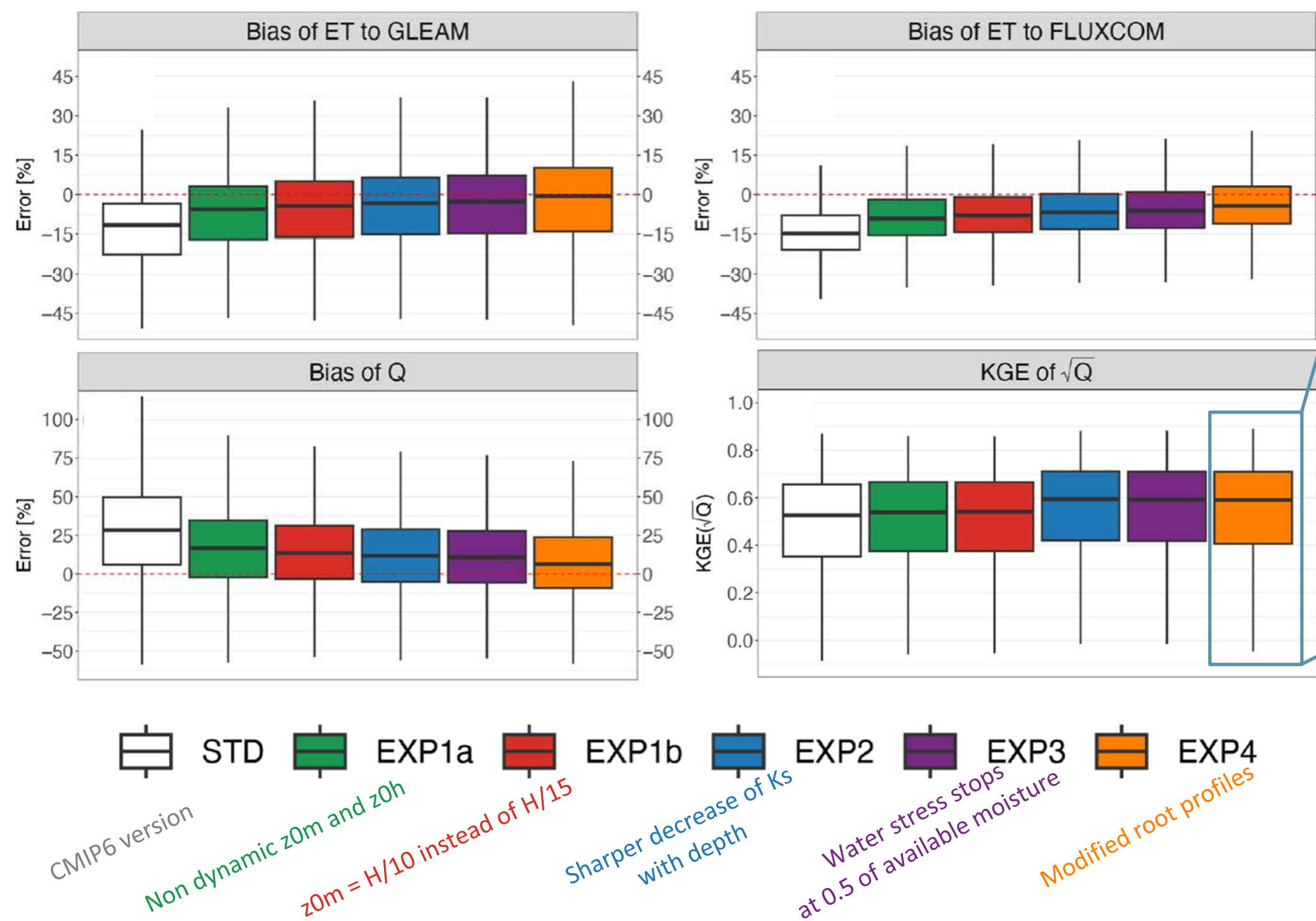


- **ORCHIDEE** land surface model developed by IPSL that represents water, energy and carbon budgets
- **Climate forcings**
 - Safran reanalysis over France produced by Météo-France (hourly, 8-km) from 1958 onwards
 - Historical CO₂ concentration
- **Hydrography**
 - High-resolution river routing derived from a 2-km DEM (Yamazaki et al., 2019)
- **Boundaries**
 - Soil texture map with 12 USDA classes from Reynolds et al. (2000)
 - Annual land cover maps with 15 PFTs from LUH2 (Hurtt et al., 2020)

Contributions from IPSL: ORCHIDEE calibration & evaluation

Benchmarks: daily Q records from the French national dataset Hydro-Portail, two ET products GLEAM and FLUXCOM

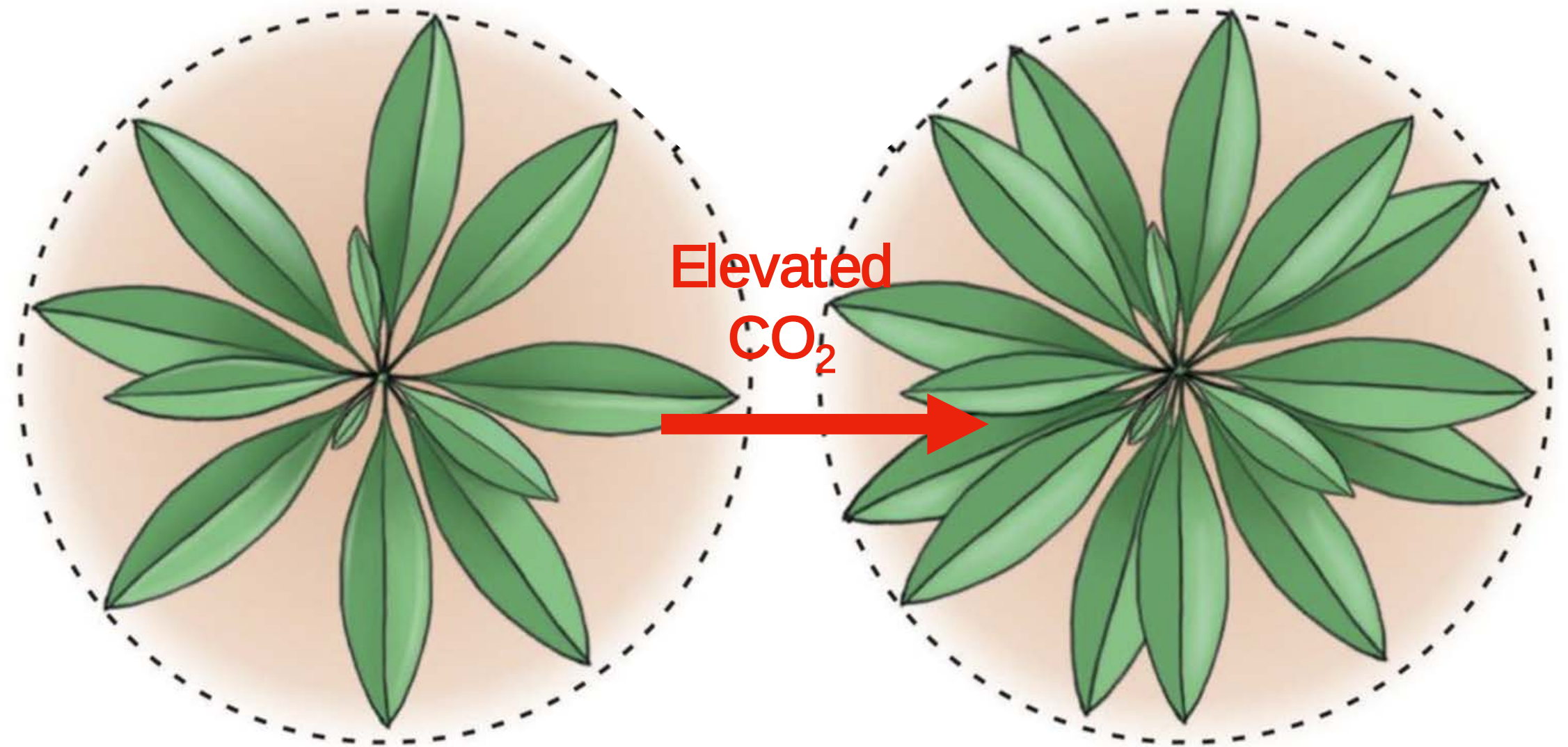
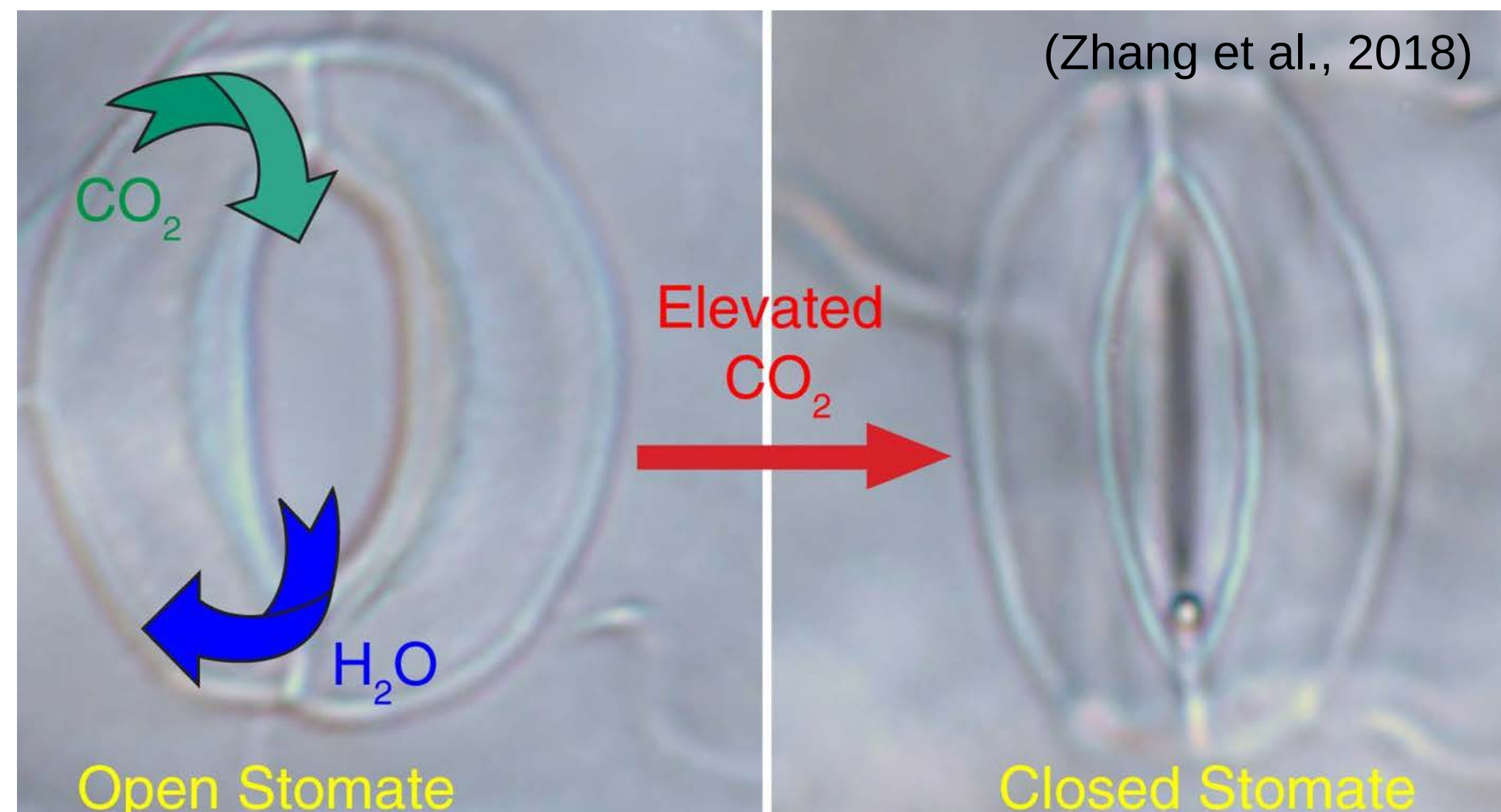
Mannual calibration of ORCHIDEE to reduce the biases of both Q and ET



This setup of ORCHIDEE is used to produce hydrological projections for the Explore2 project but with a fixed land cover map of year 2005

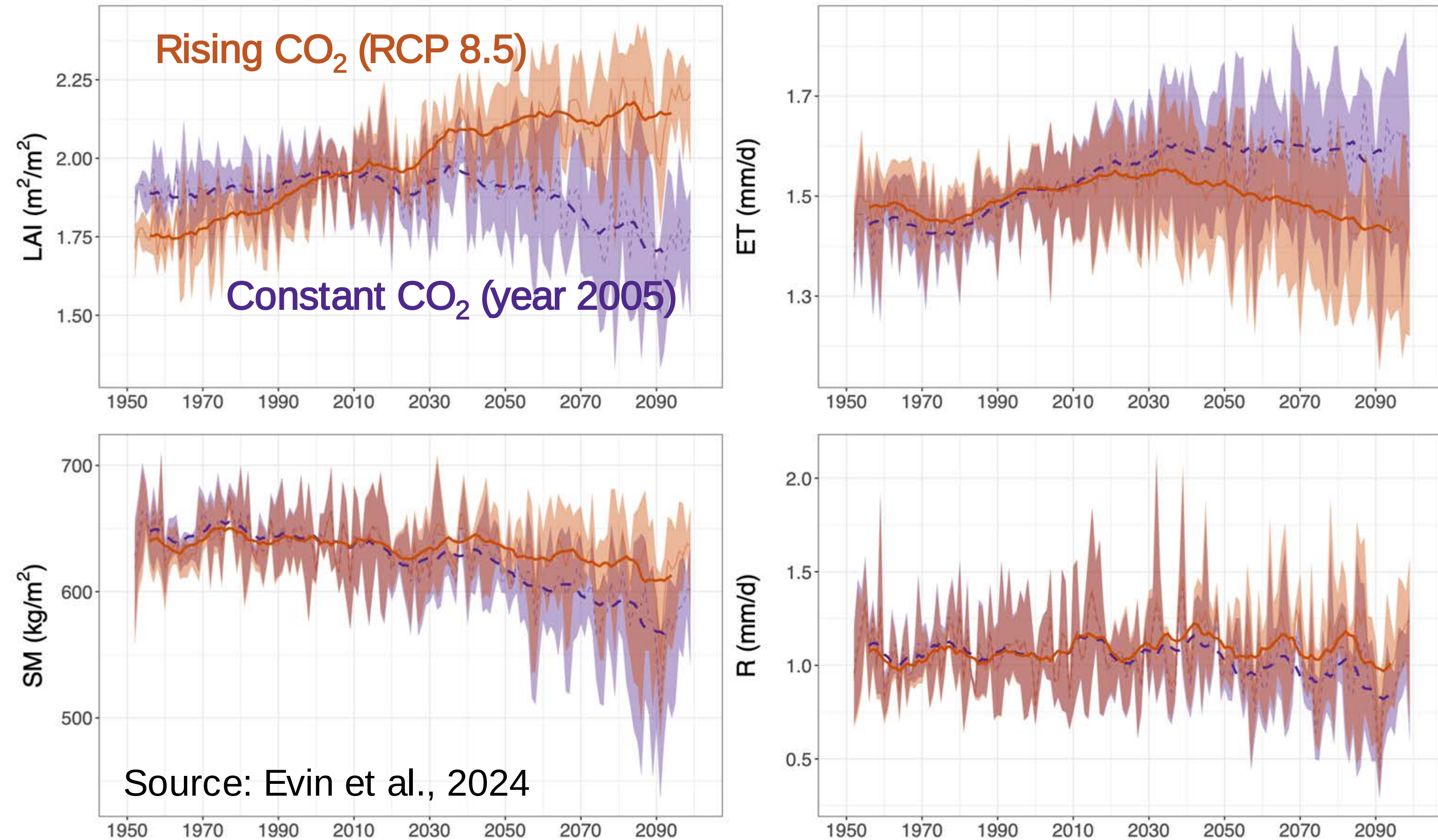
Contributions from IPSL: physiological effects of CO₂

- At vegetation level, elevated CO₂ in the atmosphere concurrently:
 - closes partially leaf stomata
(**anti-transpiration effect**)
 - enhances photosynthesis
(**fertilization effect**)



- ORCHIDEE is the only HM that accounts for the physiological effects of rising CO₂ in the Explore2 project
- Hydrological response to the physiological effects of CO₂ in France?

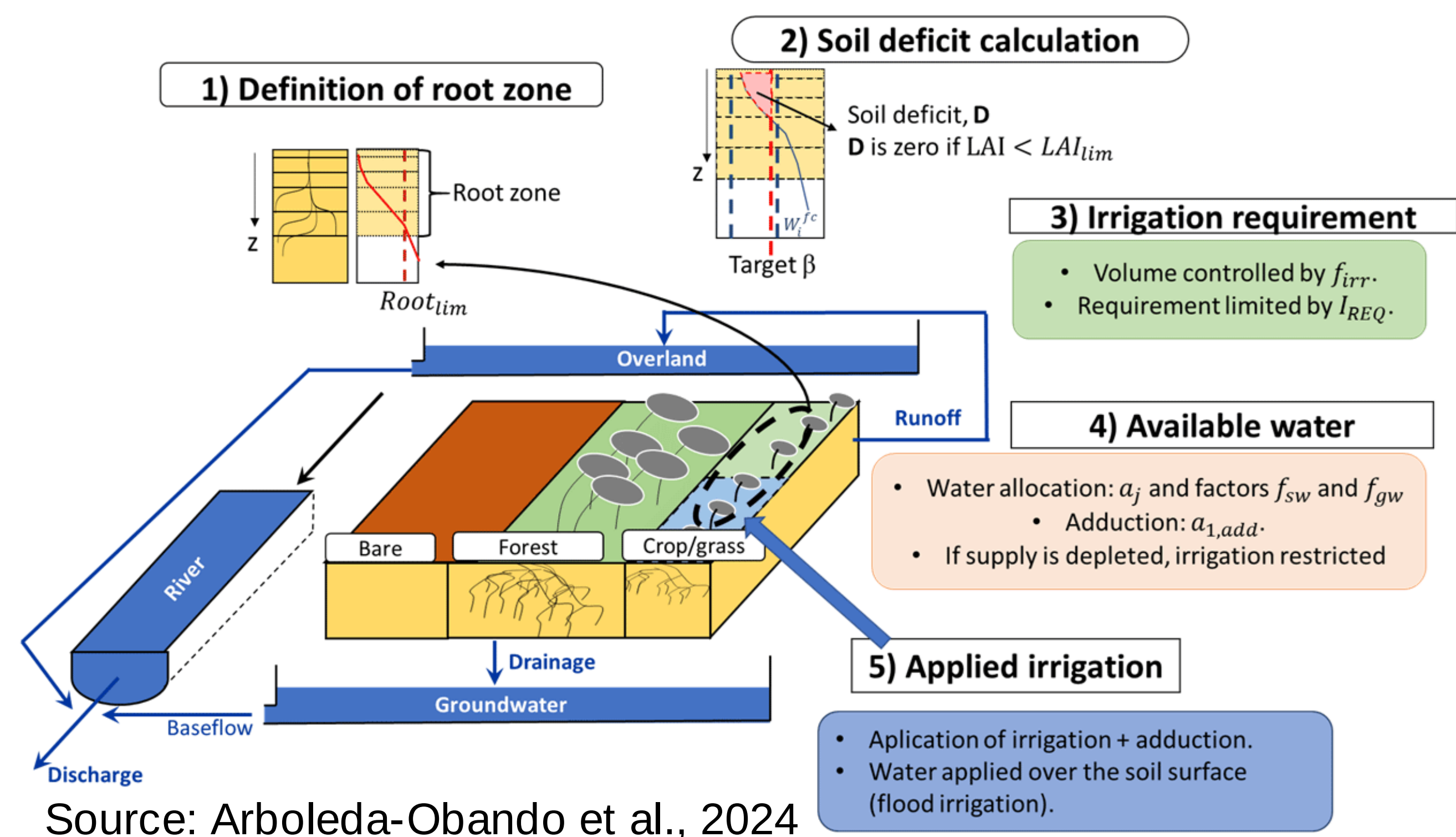
Contributions from IPSL: physiological effects of CO₂



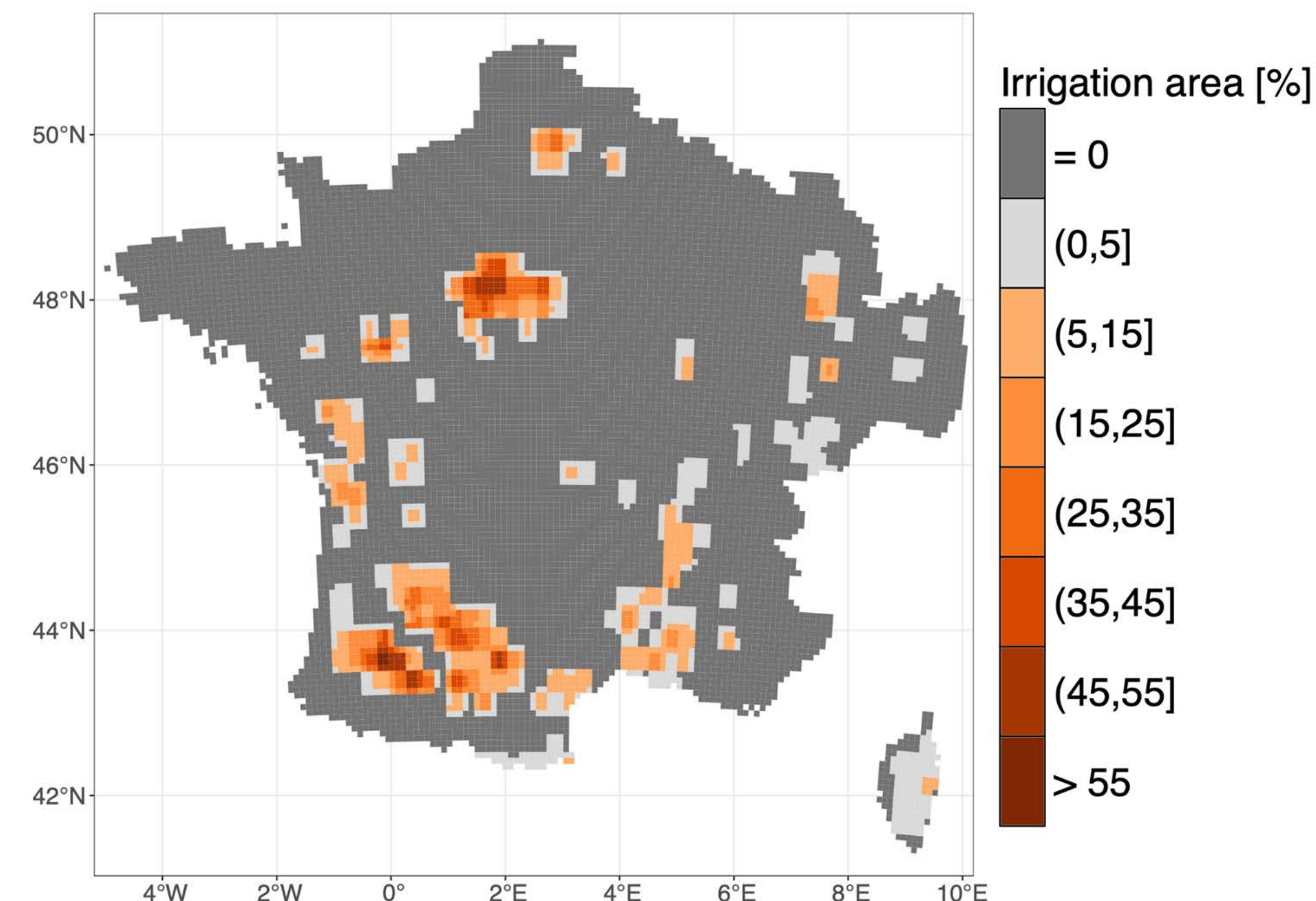
Annual changes of LAI, ET, SM and R under RCP 8.5 averaged over France

- Rising CO₂ vs constant CO₂
 - Higher leaf area index (LAI) due to fertilization effect
 - Lower evapotranspiration (ET) mainly due to anti-transpiration effect
 - Higher soil moisture (SM) and total runoff (R) due to decreased ET
- This partly explains why ORCHIDEE exhibits a relatively wetter future than the other HMs in the Explore2 project (Evin et al. 2024)

Contributions from IPSL: impact of irrigation

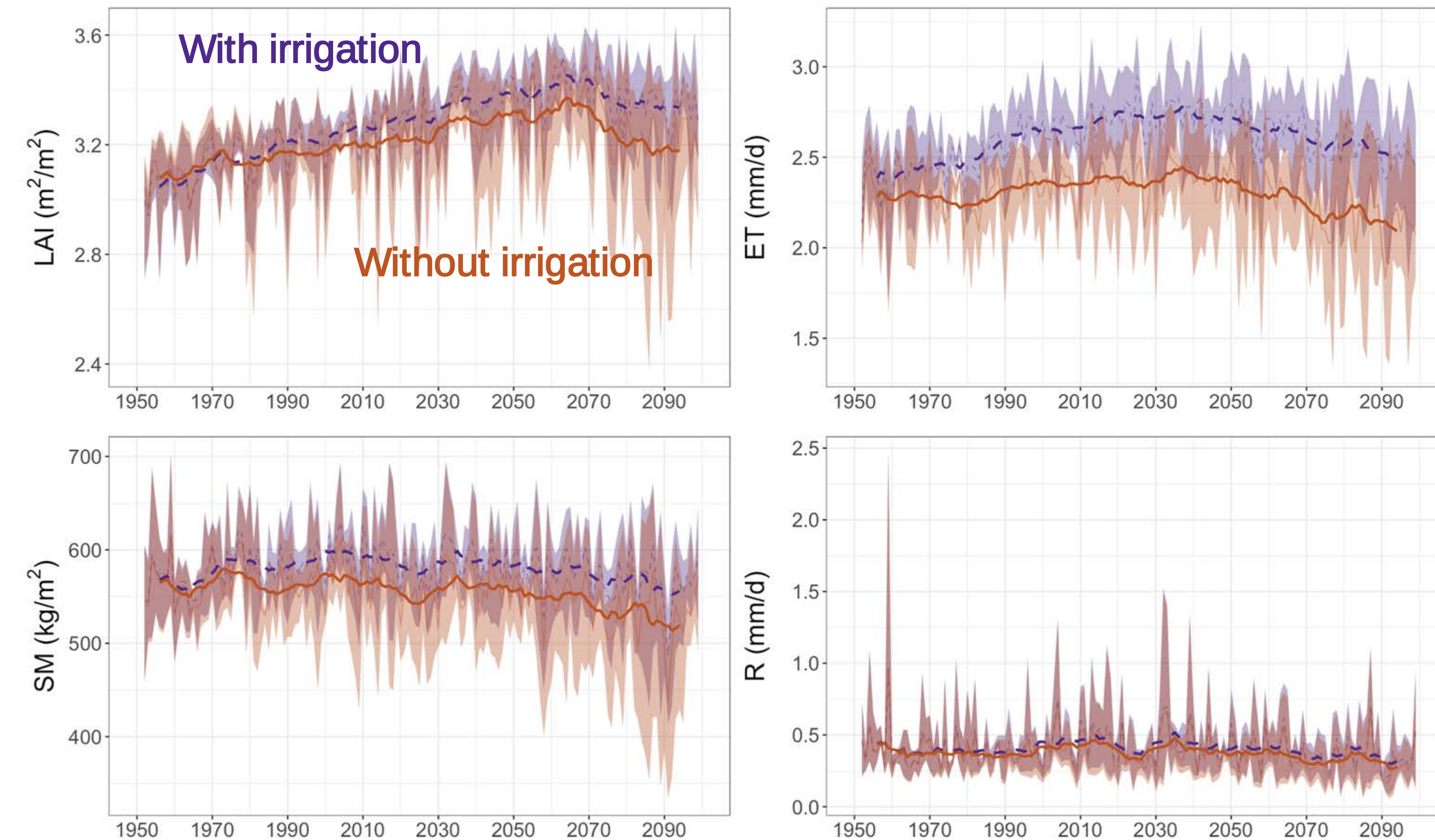


A new irrigation module in ORCHIDEE
developed by Arboleda-Obando et al. (2024)



Irrigation map of France in 2005
from LUH2 (Hurtt et al., 2020)

Contributions from IPSL: impact of irrigation

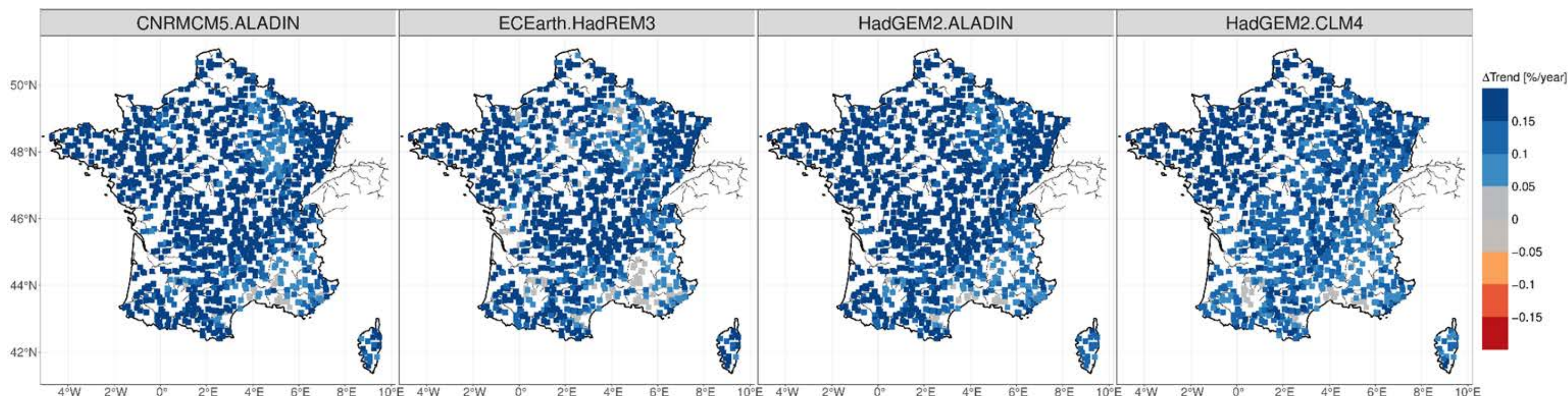


- Irrigation increases LAI, ET, SM and R (slightly) in the irrigated area in France

Summer (JJA) changes of LAI, ET, SM and R
under RCP 8.5 averaged over irrigated area (>5%) in France

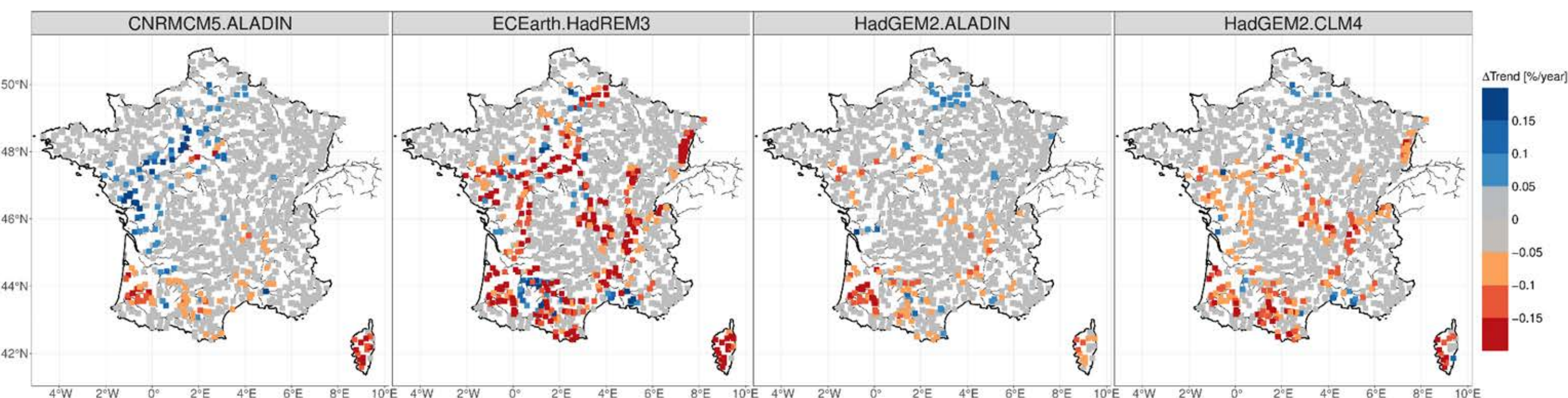
Contributions from IPSL: CO2 vs irrigation under climate change

Physiological effects of CO₂ on summer Q trends
over 2005-2099 in France under RCP 8.5



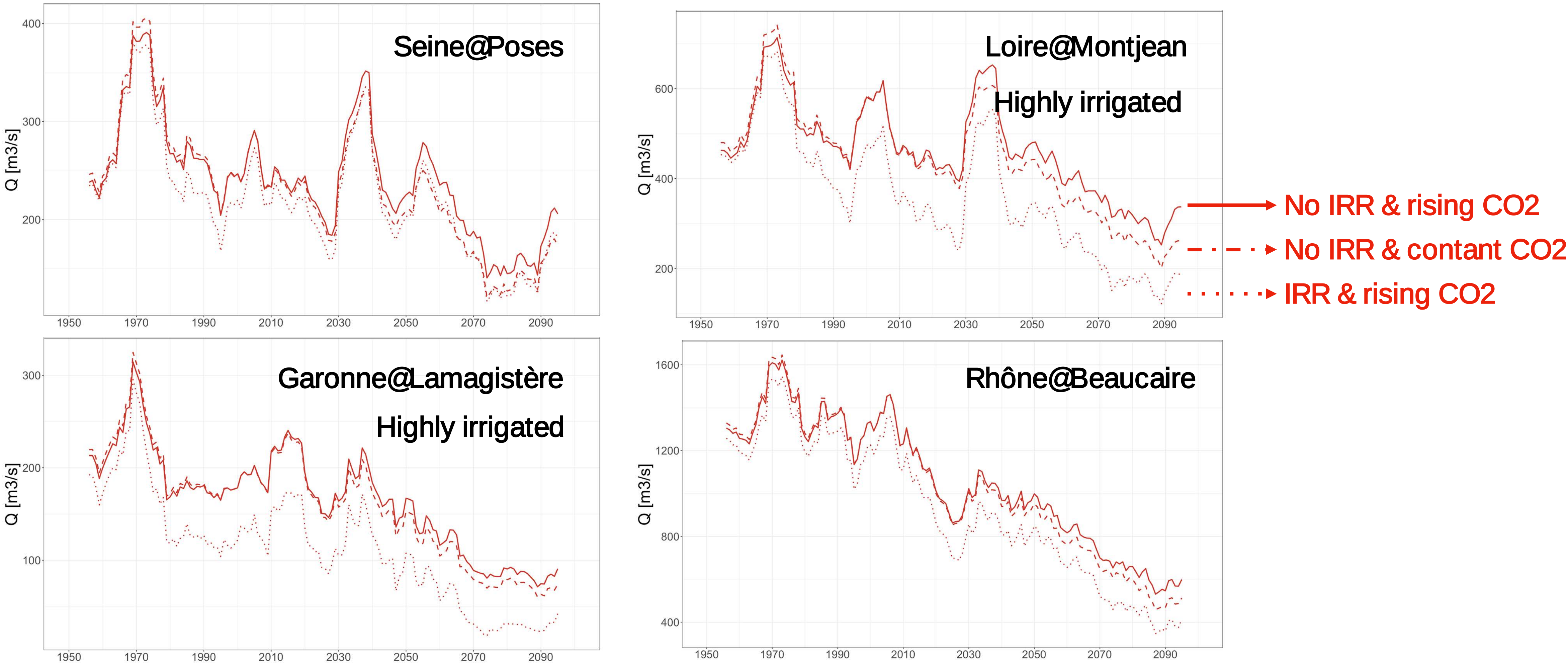
- The physiological effects of CO₂ increases summer flows all over France

Irrigation impact on summer Q trends
over 2005-2099 in France under RCP 8.5



- Irrigation decreases summer flows in general but with some local increases in the irrigated area

Contributions from IPSL: CO2 vs irrigation under climate change



Projections of summer flows for the four main river basins in France
under a hot and dry storyline (ECEarth.HadREM3 & RCP 8.5)

Conclusions and next steps

- The Explore2 project has produced a large ensemble of hydrological projections to investigate the impact of climate change on water resources in France
- This project stands out due to the extensive number of river basins studied, the diversity of models used, the accessibility of results, and the emphasis on knowledge transfer for water managers.
- IPSL provides new insights based on ORCHIDEE projections: the physiological effects of CO₂ and irrigation impacts on French water availability
- Next steps: to commit this ORCHIDEE version on SVN, publications, etc.