Probabilistic modeling of multiple spatial hazards

Application to agricultural droughts, hydrological droughts and fire weather

B. Renard[1] R. Barbero[1] I. Goukouni[1] J.-P. Vidal[2] L. Mimeau[2] C. Furusho-Percot[3] I. García de Cortázar-Atauri[3] M. Aubry[3] T. Opitz[4] D. Allard[4]

1. INRAE, Aix Marseille Univ, RECOVER, Aix-En-Provence, France. benjamin.renard@inrae.fr 2. INRAE, UR RIVERLY, Villeurbanne, France 3. INRAE, UR AgroClim, Avignon, France 4. INRAE, UR BioSP, Avignon, France

1 Introduction

2022 was an exceptionally dry, hot and fire-prone year

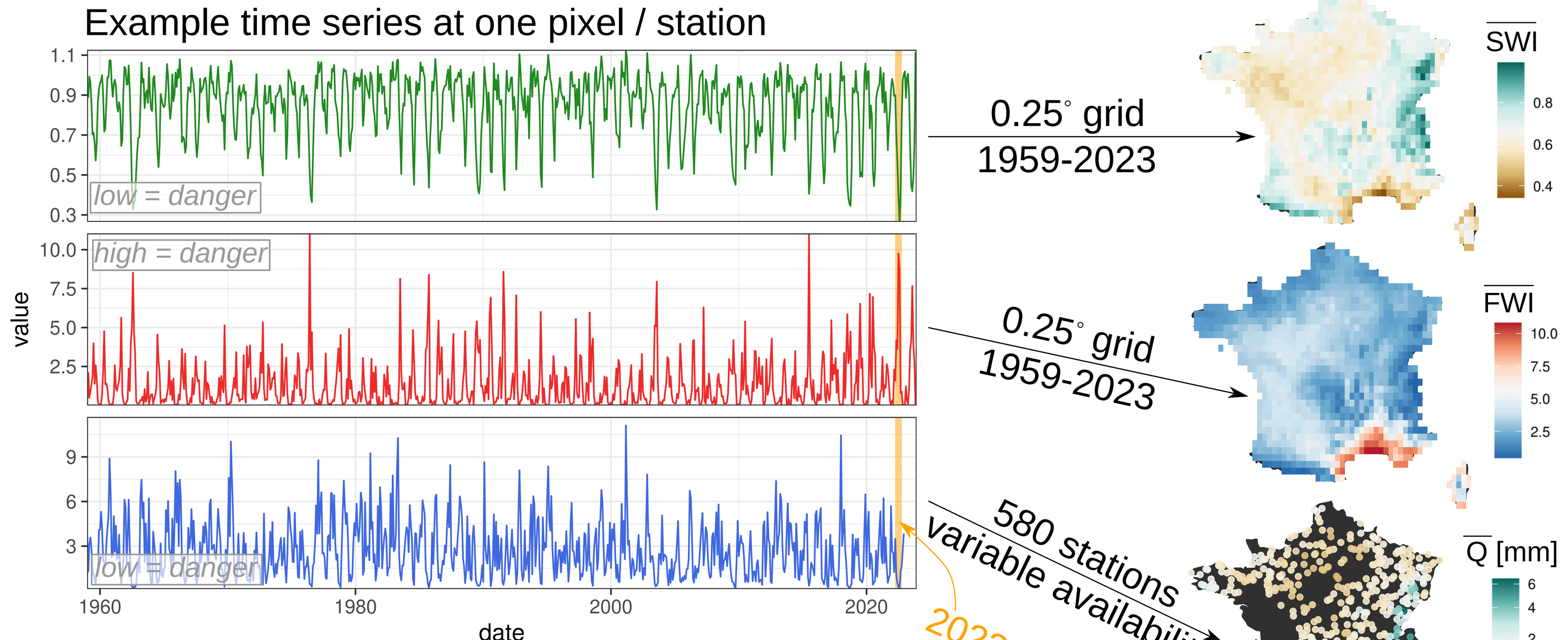
⇒ impacts: dry soils, low river flows, wildfires...

Impacts occurring **together**, over a large **spatial extent**


What was the probability of the 2022 event?
What was it 70 years ago, what will it be in 70 years?

2 Data

Monthly data for 3 variables: 1. SWI (Soil Wetness Index[1]) 2. FWI (Fire Weather Index[2]) 3. Q (river streamflow)

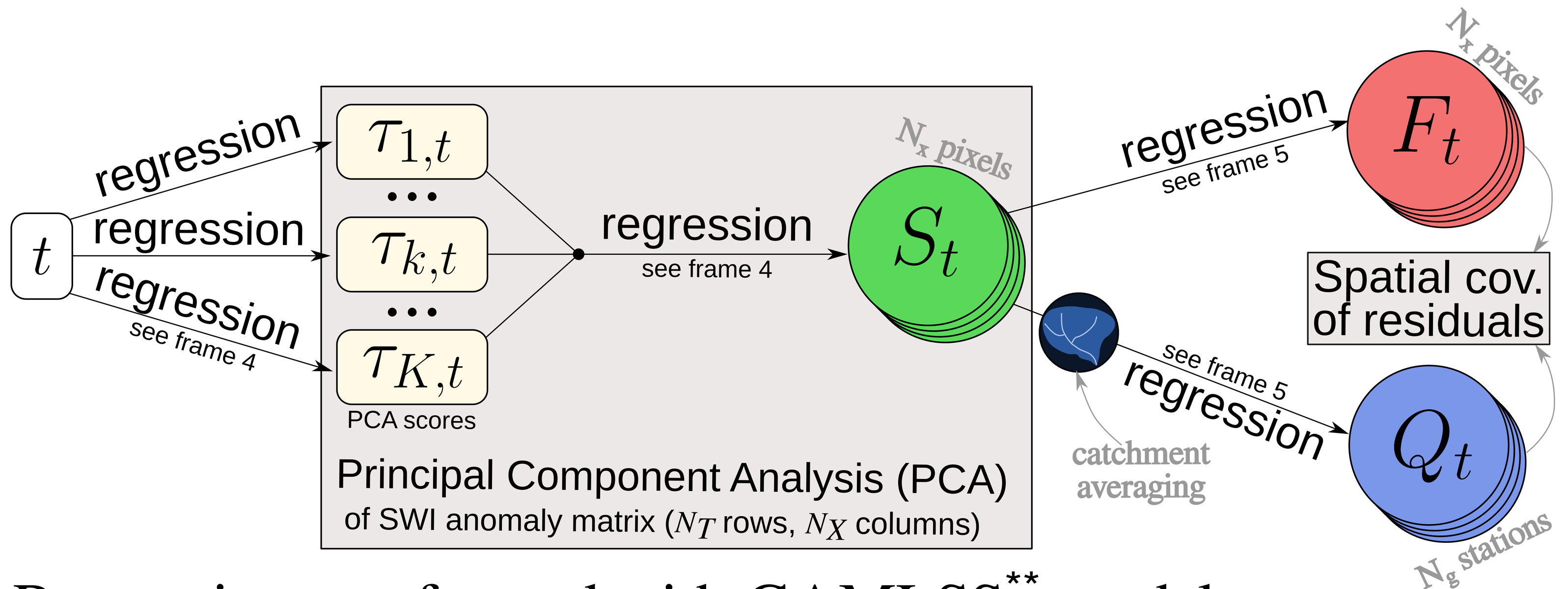


[1] Vidal et al. (**2010**). Multilevel and multiscale drought reanalysis over France with the Safran-Isba-Modcou hydrometeorological suite. *Hydrol. Earth Syst. Sci.*
Le Moigne et al. (**2020**). The latest improvements with SURFEX v8.0 of the Safran–Isba–Modcou hydrometeorological model for France. *Geosci. Model Dev.*

[2] Van Wagner (**1987**). Development and structure of the canadian forest fire weather index system. *Canadian Forest Service.*

3 Model Overview: SWI drives FWI and Q

Standardized monthly anomalies*: S_t , F_t , Q_t $(t = 1,...,N_T = 12\text{x}65)$



Regressions performed with GAMLSS** models

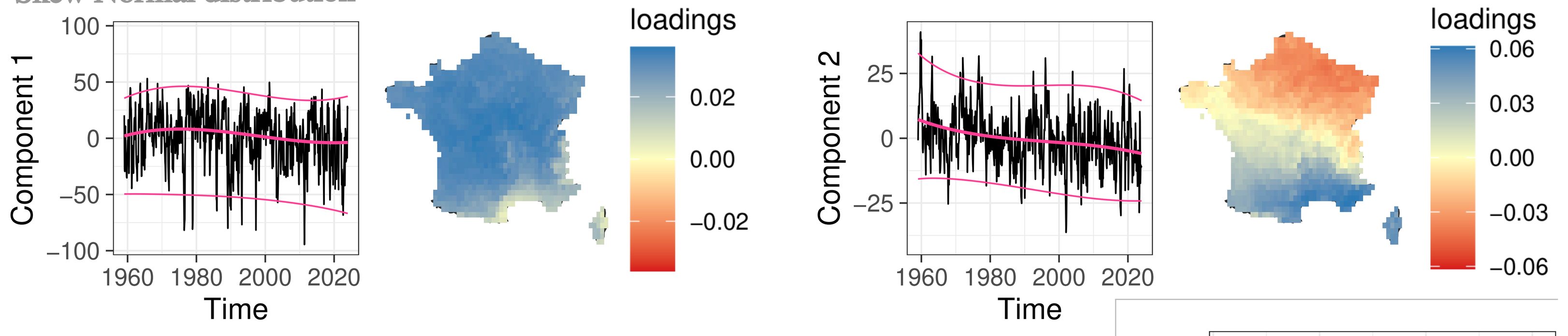
$^*a = \frac{\log(\text{raw}) - m_{\log}}{s_{\log}}$

** Stasinopoulos and Rigby (**2007**). Generalized additive models for location scale and shape (GAMLSS) in R. *Journal of Statistical Software.*

4 Principal components of SWI

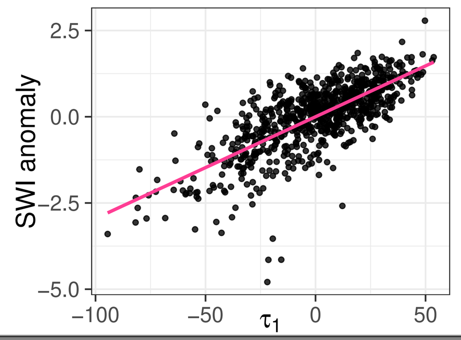
$\tau_{k,t} \sim \mathcal{SN}\left(\mu = \text{poly}(t); \log(\sigma) = \text{poly}(t); \xi\right)$ shape parameter (skew)

Skew Normal distribution



etc. up to $K = 6$ components
(chosen so as to explain 80% of total variance)

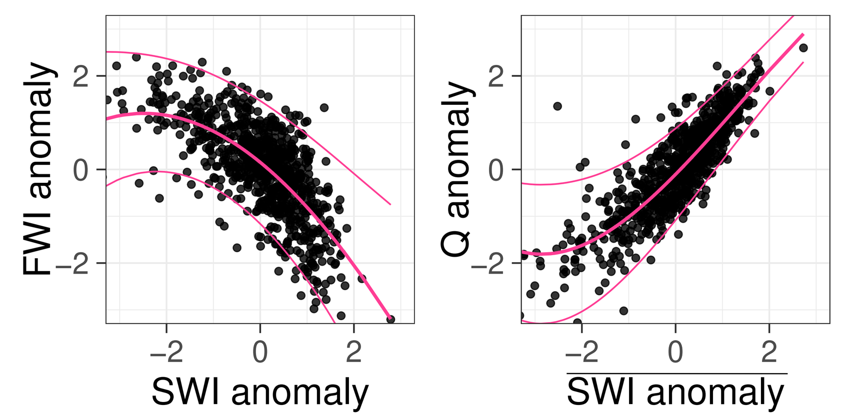
$S_t \sim \mathcal{N}\left(\mu = \text{linear}\left(\tau_{1,t}, \ldots, \tau_{K,t}\right); \sigma\right)$



5 Conditional models for FWI and Q

$F_t \sim \mathcal{N}\left(\mu = \text{poly}\left(S_t\right); \log(\sigma) = \text{poly}\left(S_t\right)\right)$

Same for Q_t
(with catchment-averaged S_t)

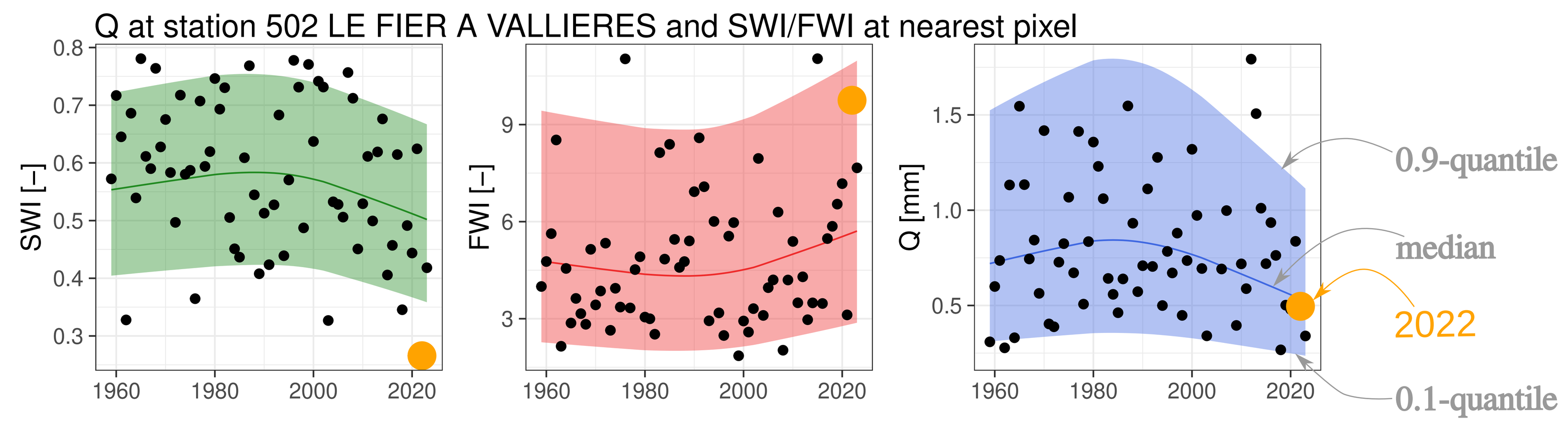


6 Time-varying distributions

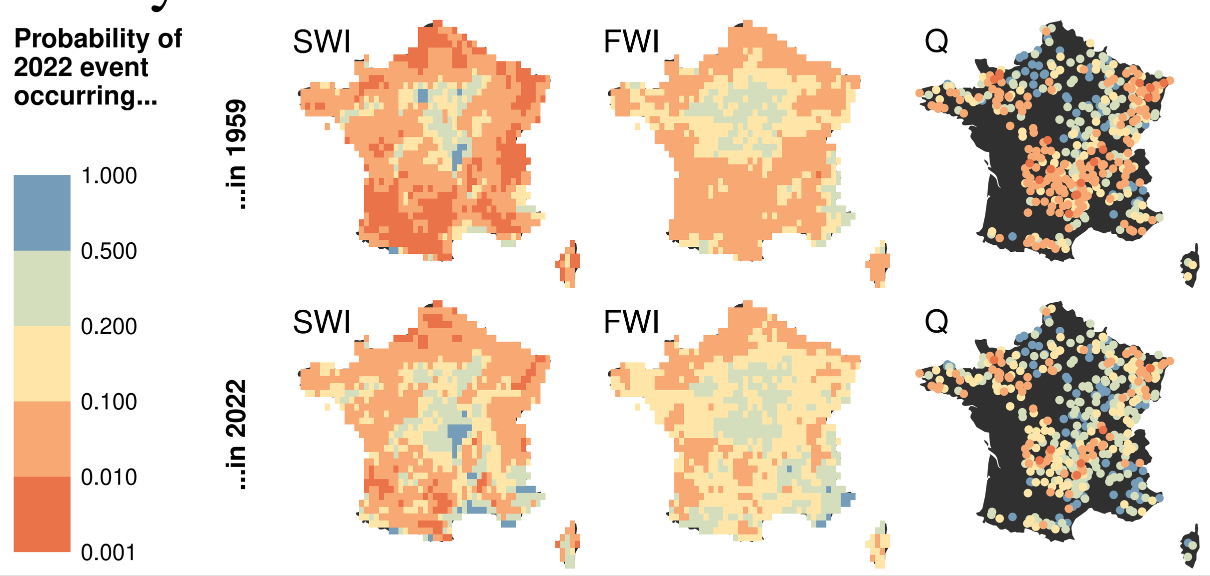
Use model to generate many realizations of $\widetilde{\tau} \rightarrow \widetilde{S} \rightarrow \widetilde{F}, \widetilde{Q}$

⇒ explore time-varying joint distribution of $\left(\widetilde{S}, \widetilde{F}, \widetilde{Q}\right)$

Example at one station / pixel :

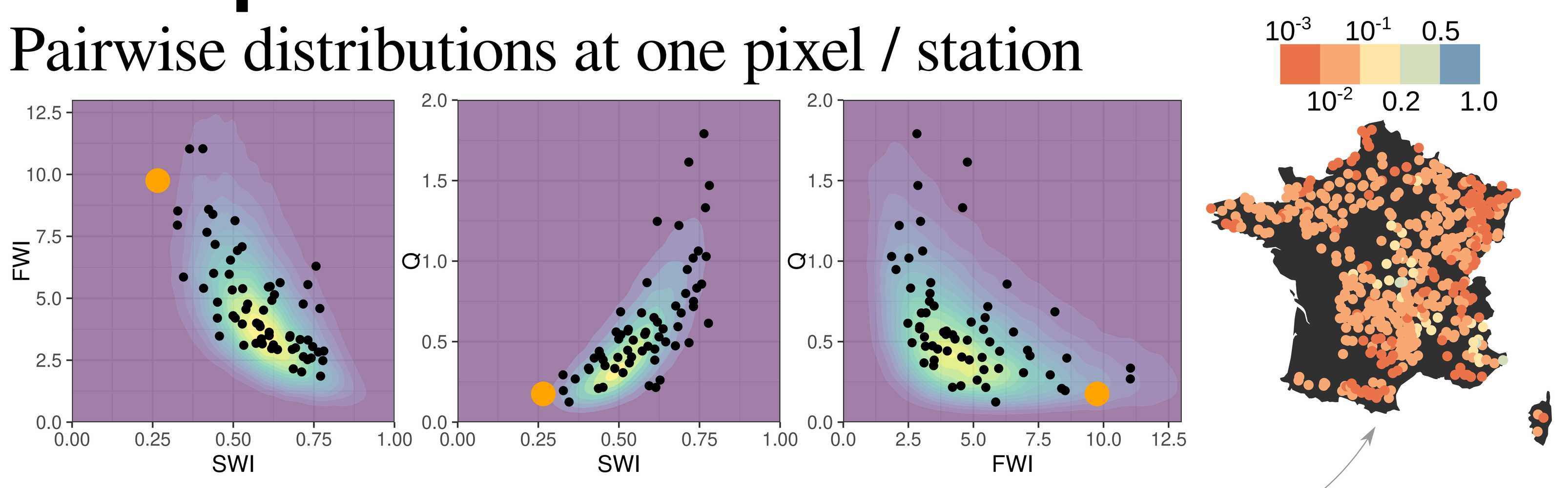


⇒ probability of 2022 event



7 Joint probabilities

Pairwise distributions at one pixel / station

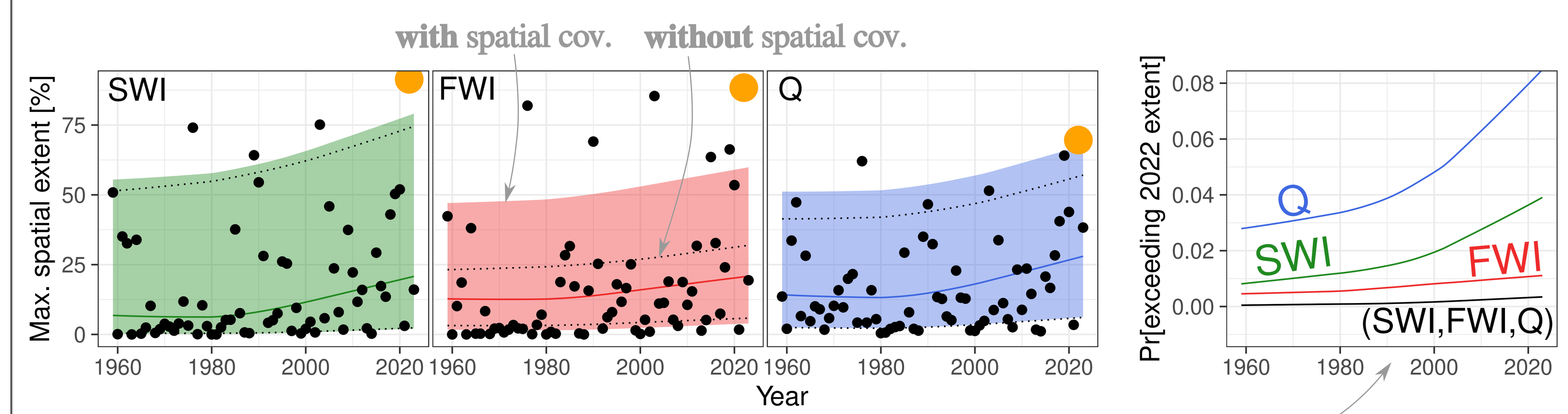


⇒ probability of jointly exceeding 2022 event

$Pr[SWI \le SWI_{2022}, FWI \ge FWI_{2022}, Q \le Q_{2022}]$

8 Spatial extents

% of pixels / stations exceeding a 5-year event (empirical 0.2-quantile)

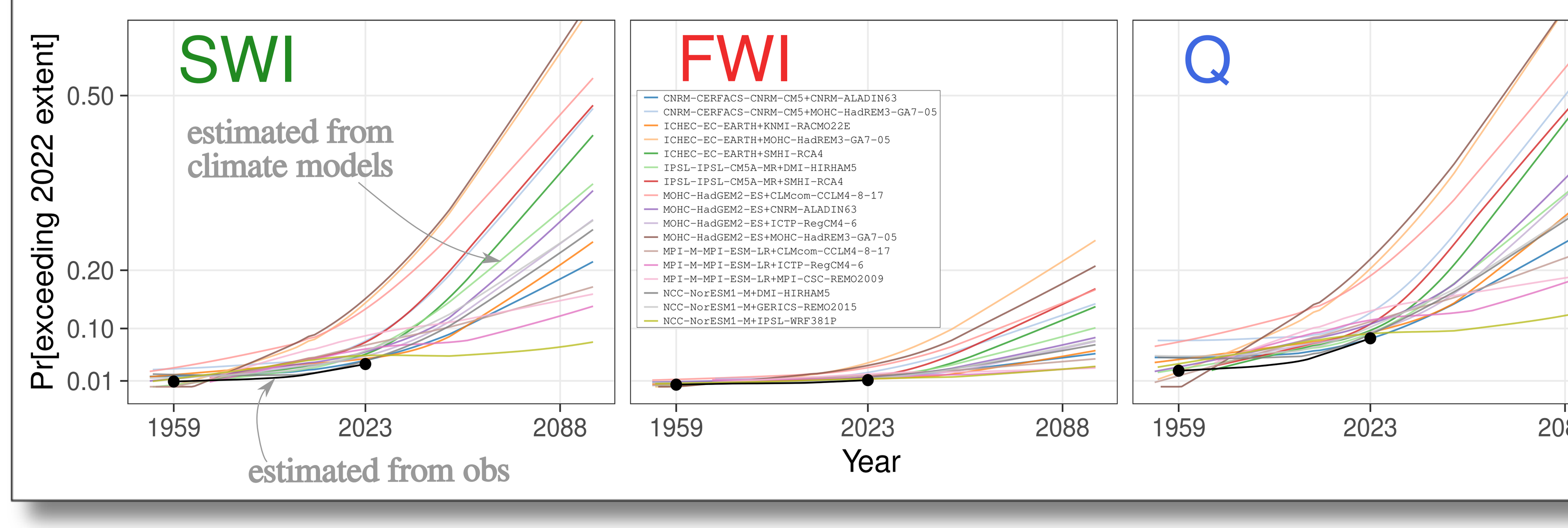


⇒ probability of exceeding 2022 extent

9 Future projections

Future SWI from 17 GCM/RCM combinations
EURO-CORDEX, RCP8.5, https://www.drias-eau.fr/

Projection in PCA basis ⇒ simulate from $\widetilde{\tau}_{\text{future}} \rightarrow \widetilde{S} \rightarrow \widetilde{F}, \widetilde{Q}$



10 Conclusions

A combination of simple models is able to describe the multivariate space-time variability of SWI, FWI and Q.

Hazard can be characterized in terms of marginal intensity, joint occurrence, spatial extent and duration (not shown).

The 2022 event would have been exceptionnal in the 1960s; it was extreme when it occurred; it will be fairly usual by 2100.

Future work: theoretical properties of extremes? applicability to other multiple hazards? practical applications?