Sustainability of bread wheat in France: a GAMLSS-based risk and return period assessment

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1 Context

Wheat yields in France have stagnated since the 1990s, with several **exceptionally low-yield years** in the past two decades (**2003, 2007, 2016, 2024**) largely explained by adverse climate condition*. To develop effective adaptation strategies, it is crucial to understand how climate-related risks to crops are evolving over time to prioritize effective adaptation strategies. **Indicator-based approaches** have been widely used to assess future climatic risks to agriculture**. However, few studies have investigated how the probability of these risks changes over time. **How will the frequency of past extreme climatic events evolve in the future and threaten crop suitability ?**

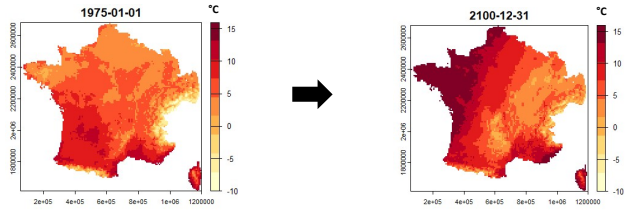
*Ben Ari et al. (**2018**) Causes and implications of the unforeseen 2016 extreme yield loss in the breadbasket of France

Harkness et al. (2020**) Adverse weather conditions for UK wheat production under climate change

2 Data

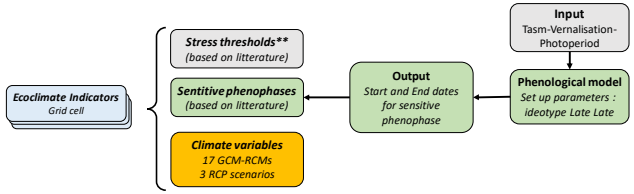
Daily gridded (8x8 km grids from project Explore2) climate variables (Tasm, Tasn, Tasx, rainfall, ETP, and Hr) from 1975 to 2100, based on 17 GCM-RCM combinations and three emission scenarios (RCP 2.6, 4.5 8.5).

Example : Daily maximal temperature (Tasx) from GCM-RCM : CNRM_CERFACS_CNRM_CM5-CNRM_ALADIN63 and scenario RCP 8.5

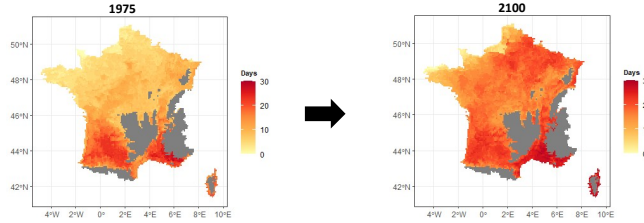


3 Ecoclimate indicators computing

Using climate variables, yearly ecoclimate indicators* are calculated at a sub-500 m grid resolution during the critical phases of the wheat growing season, based on a late-maturing wheat ideotype to inform phenological model parameterisation in terms of temperature requirement



Example : Heat stress indicator (nbr days with Tasx >25°C) during grain filling phase from GCM-RCM: CNRM_CERFACS_CNRM_CM5-CNRM_ALADIN63 and scenario RCP 8.5



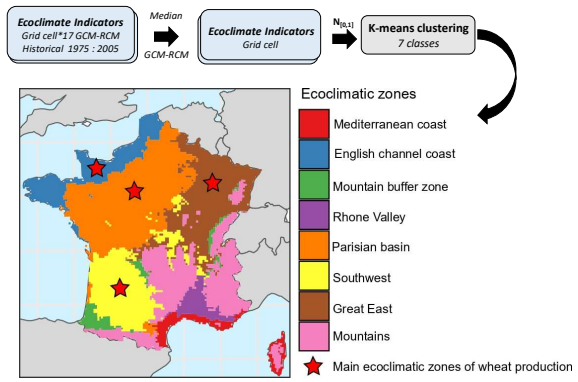
* Le Roux et al. (**2024**) Mapping the race between crop phenology and climate risks for wheat in France under climate change

* Caubel et al (**2015**) Broadening the scope for ecoclimatic indicators to assess crop climate suitability according to ecophysiological, technical and quality criteria

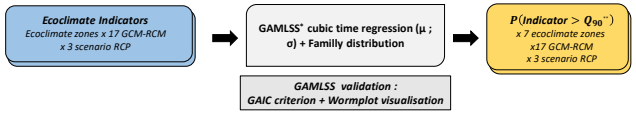
** Aubry et al (**2025**) A new dataset to elucidate inaccurate temperature thresholds masking a hidden source of risk uncertainties in common wheat

4 Ecoclimate clustering

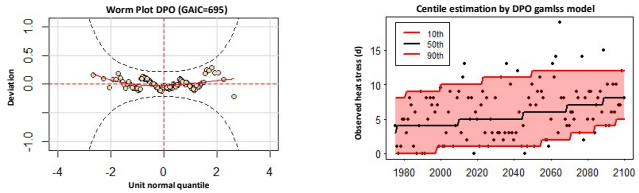
The median values of 31 annual gridded eco-climate indicators, derived from 17 GCM-RCM simulations over the historical period (1975–2005), were used as inputs for a clustering analysis. This analysis enabled the identification of seven distinct ecoclimatic zones.



5 Computing exceedance probability individual risks



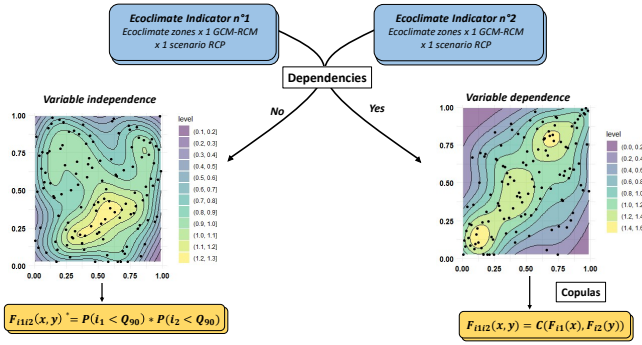
Example of GAMLSS model distribution Double Poisson for Heat stress (d >25°C) during grain filling



*Stasinopoulos and Rigby (**2007**) Generalized Additive Models for Location Scale and Shape (GAMLSS) in R

** 90th quantile Based on historical periode 1975:2005

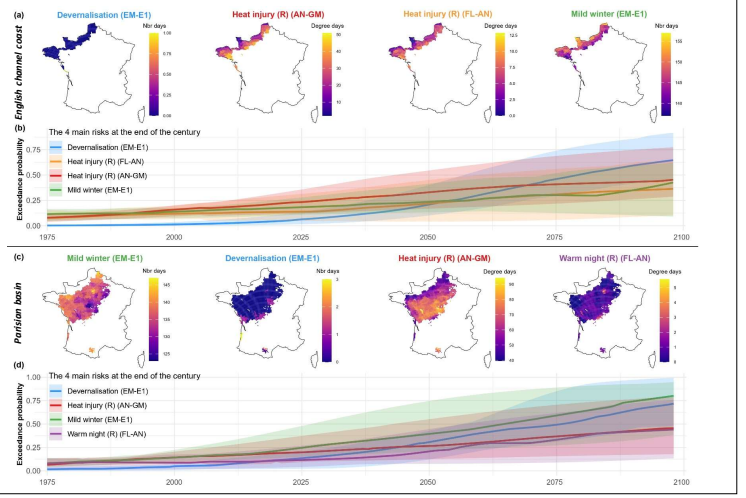
6 Computing exceedance probability compound risks



*From a cumulative distribution function (F), we can deduce the exceedance probability.

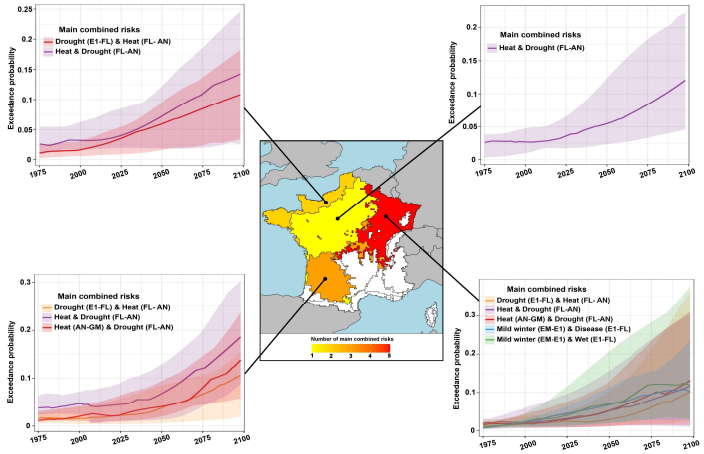
7 Main future trends in past extreme ecoclimatic risks (individual)

Example of the evolution of the probability of exceedance for the 4 highest risk evolutions for 2 ecoclimatic zones producing wheat in RCP 8.5



8 Main future trends in past extreme ecoclimatic risks (Compound)

Example for the 4 main zone producing wheat, of main compound risk evolution (i.e. exceedance probability > 0.1)



9 Conclusion

- **Generalized Additive Models for Location Scale and Shape** (GAMLSS) were used to evaluate future wheat suitability in France, based on **ecoclimatic indicators** and **exceedance probability** analysis.
- **Past temperature extremes** (>90th quantile) **between emergence (EM) to ear 1cm (E1), flag leaf (FL) to anthesis (AN) and anthesis (AN) to grain maturity (GM)** are projected to **become the norm after 2080.** In the hottest GCM-RCM scenarios, this **could happen as early as 2050**, across all ecoclimatic zones.
- **Heat stress** is expected to impact booting, heading, and grain-filling stages. **Warmer winters** may disrupt vernalisation and raise disease pressure**, especially under high rainfall or humidity from E1 to FL.**
- **Compound heat and drought risks** are likely to intensify, with at least **one severe event per decade**.
- **Adaptation strategies** should focus on improving **heat and disease resistance and lower chilling requirements**, especially **in vulnerable areas like the South-West and Grand Est**