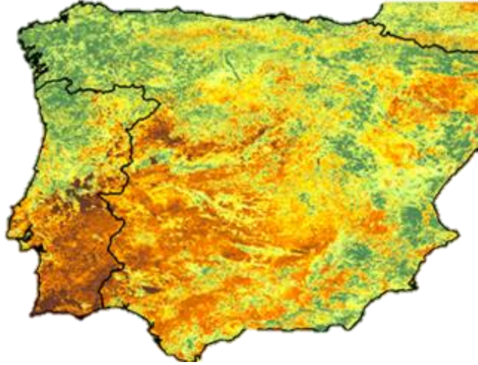
COST is supported by the EU Framework Programme Horizon 2020



Agricultural impacts of compound dry and hot extremes in the Iberian Peninsula

Andreia Ribeiro, Ana Russo, Célia Gouveia, Patrícia Páscoa, Jakob Zscheischler

Weather and Climatic Extremes: Data, Analysis and Impact – WCEDAI 2020

Introduction

Background

- Short-Term Scientific Mission Cost Action DAMOCLES (CA17109)
- Compound hot and dry extreme events – risks of crop failure
- Early information can benefit decision makers
- In previous work we found that dry conditions are major sources of risk for rainfed cropping systems

Ribeiro et al. 2019, NHESS

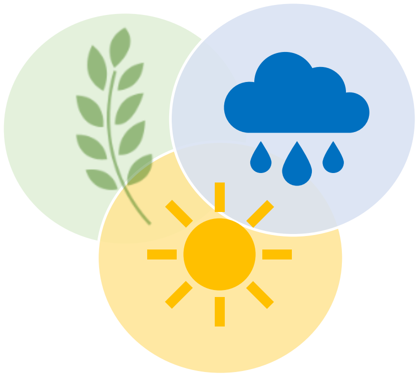
Ribeiro et al. 2019, AGWAT

A compound event perspective

- A question of interest is if extreme crop failures are attributed to a compound event

“Understanding compound events requires an analysis of the complex causal chains that can lead to extreme impacts”

Zscheischler et al. 2018, Nature Climate Change



The occurrence of hot extremes is amplifying the impact of droughts on agriculture?

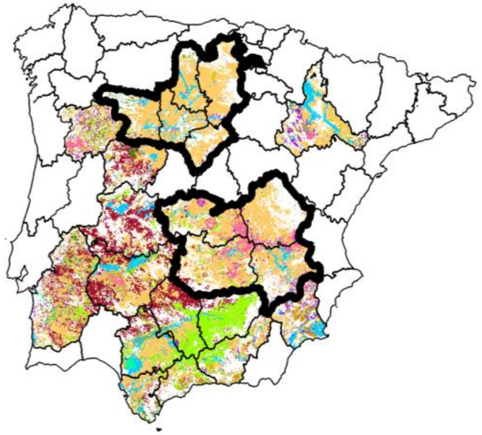
Objectives

1. Identify the dominant months of meteorological variables in explaining the variability of crop yields
2. Describe the dependence structures between the dry and hot conditions and the crop yields
3. Estimate the conditional probability of crop-loss under different hot and dry severity levels
4. Evaluate how much the compound event increases the damage in crop yield in comparison to the individual hazards

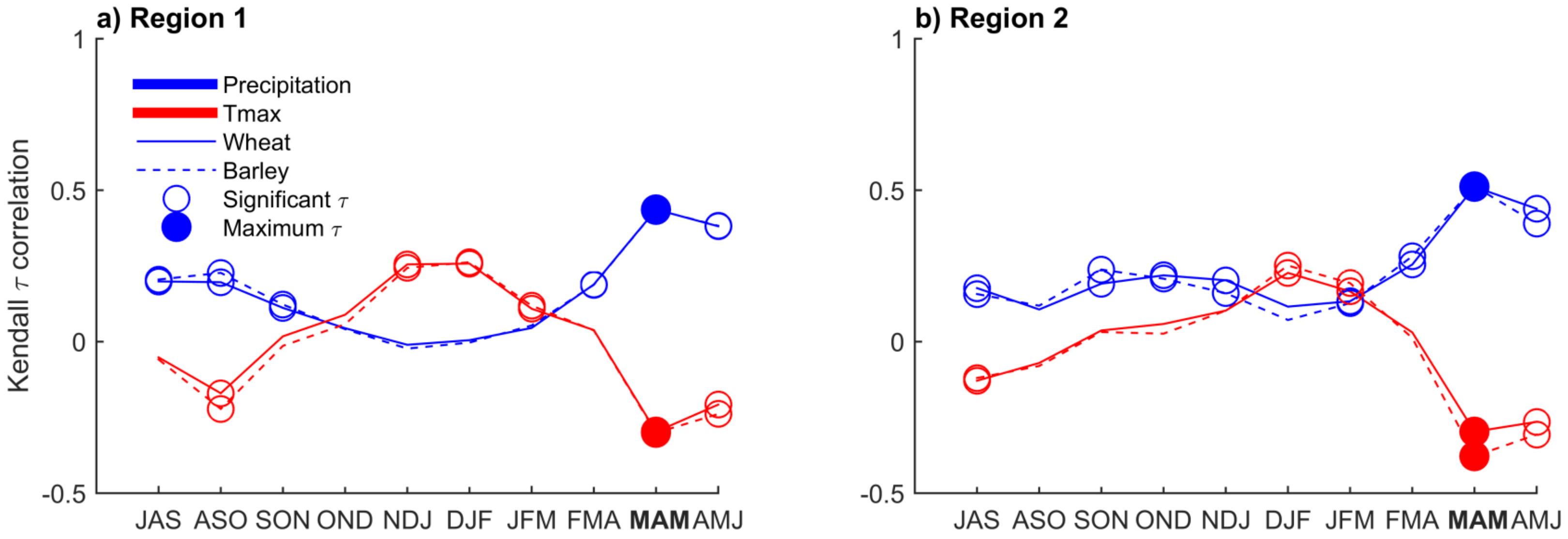
Data

- Wheat and barley yields (t/ha) 1986-2016
  - Detrend based on LOESS
- Precipitation and Temperature anomalies from CRU TS4.01
  - Moving averages with past values

Major agricultural areas



Correlation analysis



Conceptual model (trivariate case)

- Statistical approach based on copula theory to model the trivariate relationship between drought, heat and crop yields to assess how extreme crop loss is related to its interactions

Compound dry and hot extremes

Spring precipitation (P_{MAM}) – X_1
Spring maximum temperature ($Tmax_{MAM}$) – X_2

Agricultural impacts

Crop yield annual anomalies - Y

Under dry conditions

$$F_{Y|X_1}(Y|X_1 = x_1^*) = P(Y \leq y|X_1 \leq x_1^*)$$

Under hot conditions

$$F_{Y|X_2}(Y|X_2 = x_2^*) = P(Y \leq y|X_2 \leq x_2^*)$$

Under compound dry and hot conditions

$$F_{Y|X_1,X_2}(Y|X_1 = x_1^*, X_2 = x_2^*) = P(Y \leq y|X_1 \leq x_1^*, X_2 \leq x_2^*)$$

Research question:

$F_{Y|X_1,X_2}$ suggests higher probabilities of crop-loss rather than $F_{Y|X_1}$ and $F_{Y|X_2}$?

Or in other words ,

Is the risk of crop-loss under dry $F_{Y|X_1}$ or hot conditions $F_{Y|X_2}$ is amplified by their interaction $F_{Y|X_1,X_2}$?

Copula theory

A copula is a function that joins a multiple distribution function to their marginal distribution functions (Sklar, 1959)

$$F(x_1, x_2, \dots, x_d) = C(F_1(x_1), F_2(x_2), \dots, F_d(x_d))$$

Uniformly distributed variables

$u_1 = F_1$ yield

$u_2 = F_2$ precipitation

$u_3 = F_3$ temperature

Three bivariate copulas

$F_{12} = C_{12}(u_1, u_2)$

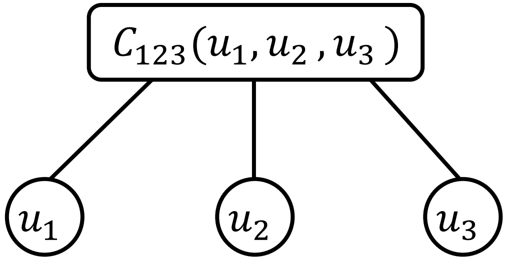
$F_{13} = C_{13}(u_1, u_3)$

$F_{23} = C_{23}(u_2, u_3)$

Trivariate copula

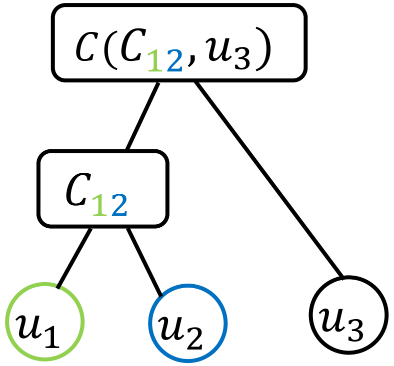
$F_{123} = C_{123}(u_1, u_2, u_3)$

1 level 3-dim copula

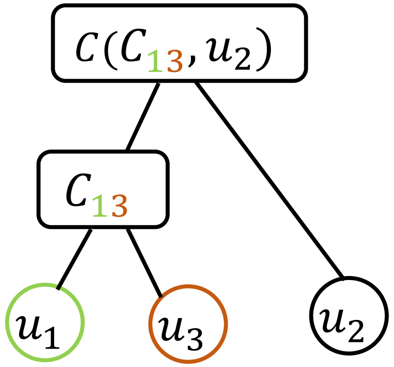


$F_{123} = C_{123}(u_1, u_2, u_3)$

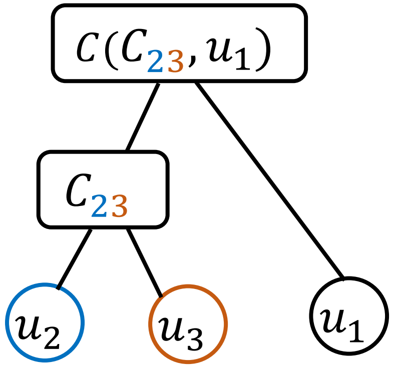
Nested Archimedean Copulas (R package HAC by Okhrin and Ristig, 2014)



$F_{123} = C[C_{12}(u_1, u_2), u_3]$



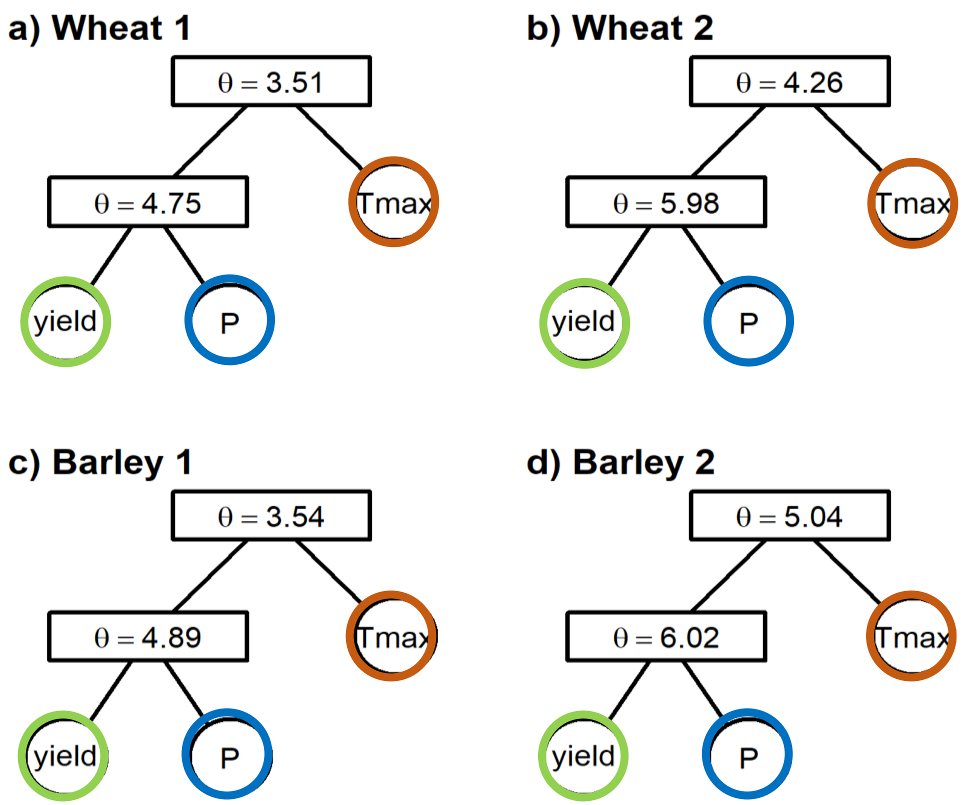
$F_{123} = C[C_{13}(u_1, u_3), u_2]$



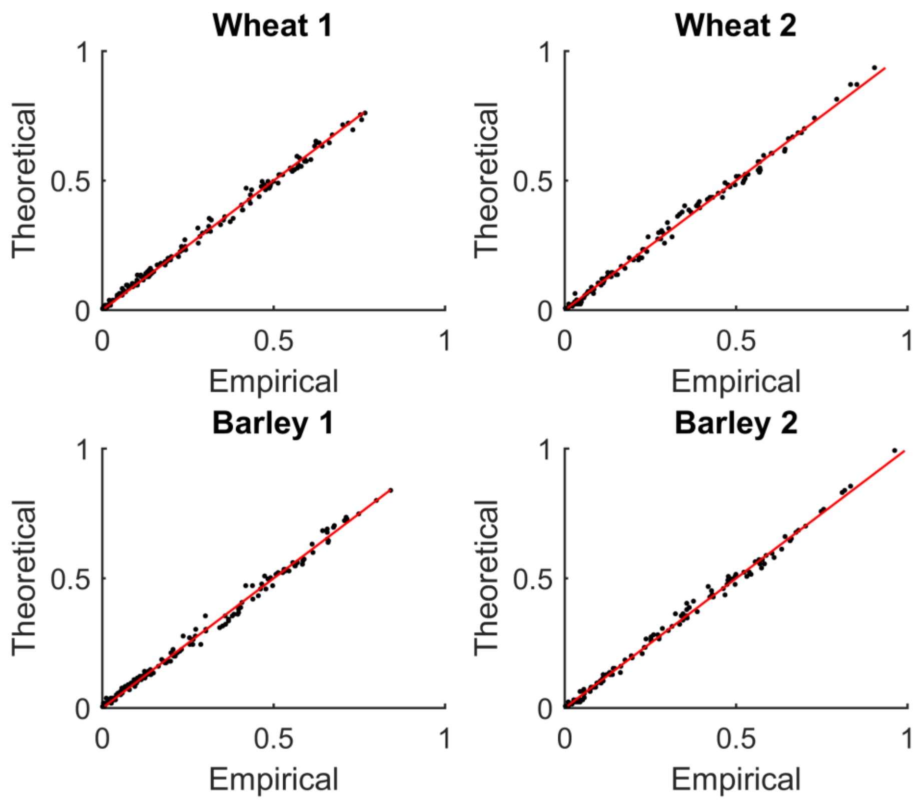
$F_{123} = C[C_{23}(u_1, u_3), u_1]$

Results

Trivariate model's structures



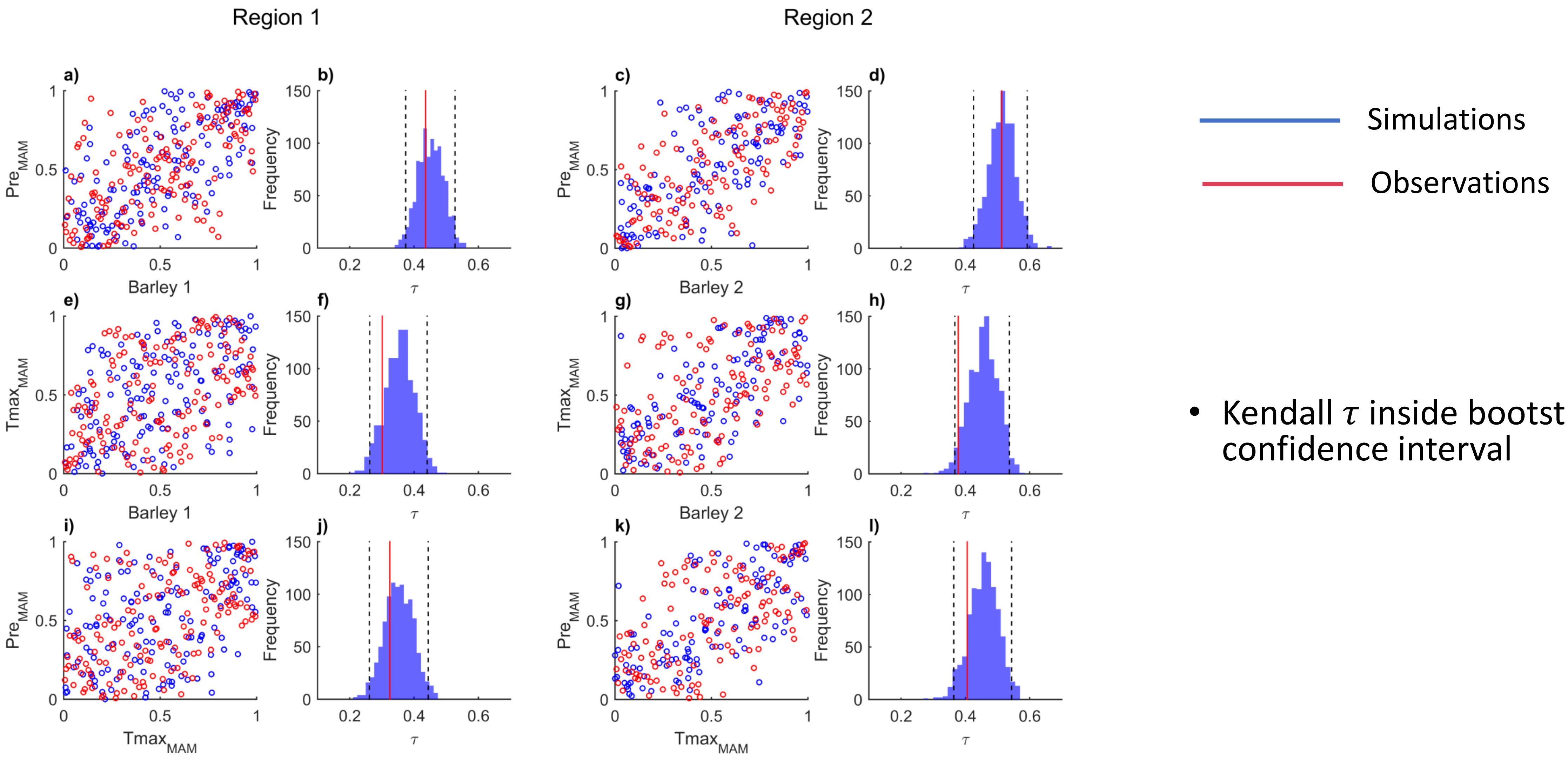
Theoretical vs empirical



- **Deeper level copula corresponds to the pair $F_{12} = C_{12}(u_1, u_2)$ in both clusters based on a Frank copula**

Results

Samples from the estimated models

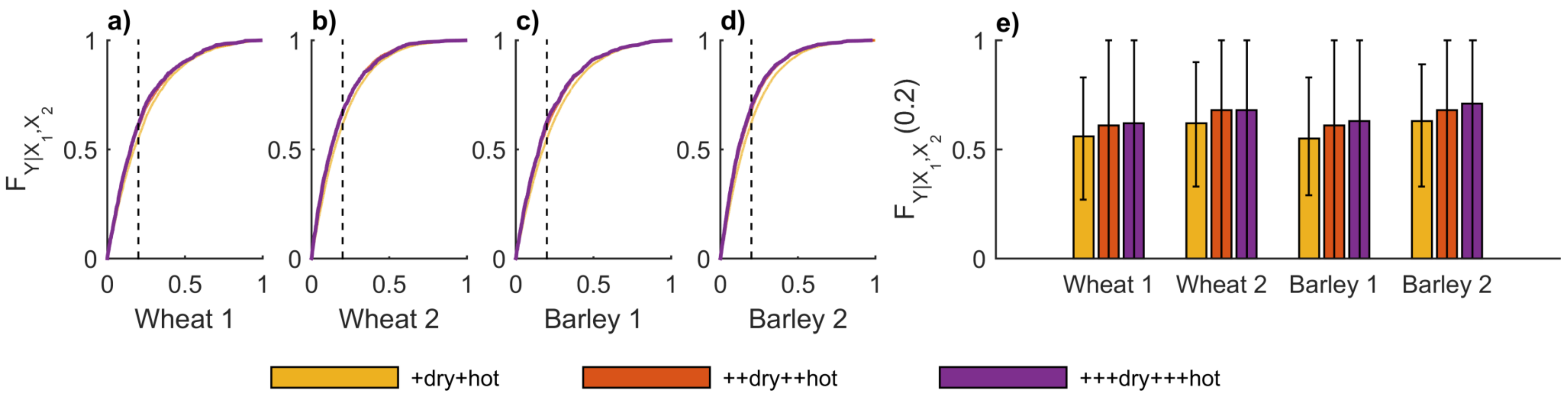


- Kendall τ inside bootstrapped confidence interval

Results

	Moderate (+)	Severe (++)	Extreme (+++)
dry	$P_{MAM} \leq 20th$	$P_{MAM} \leq 10th$	$P_{MAM} \leq 5th$
hot	$Tmax_{MAM} \geq 80th$	$Tmax_{MAM} \geq 90th$	$Tmax_{MAM} \geq 95th$

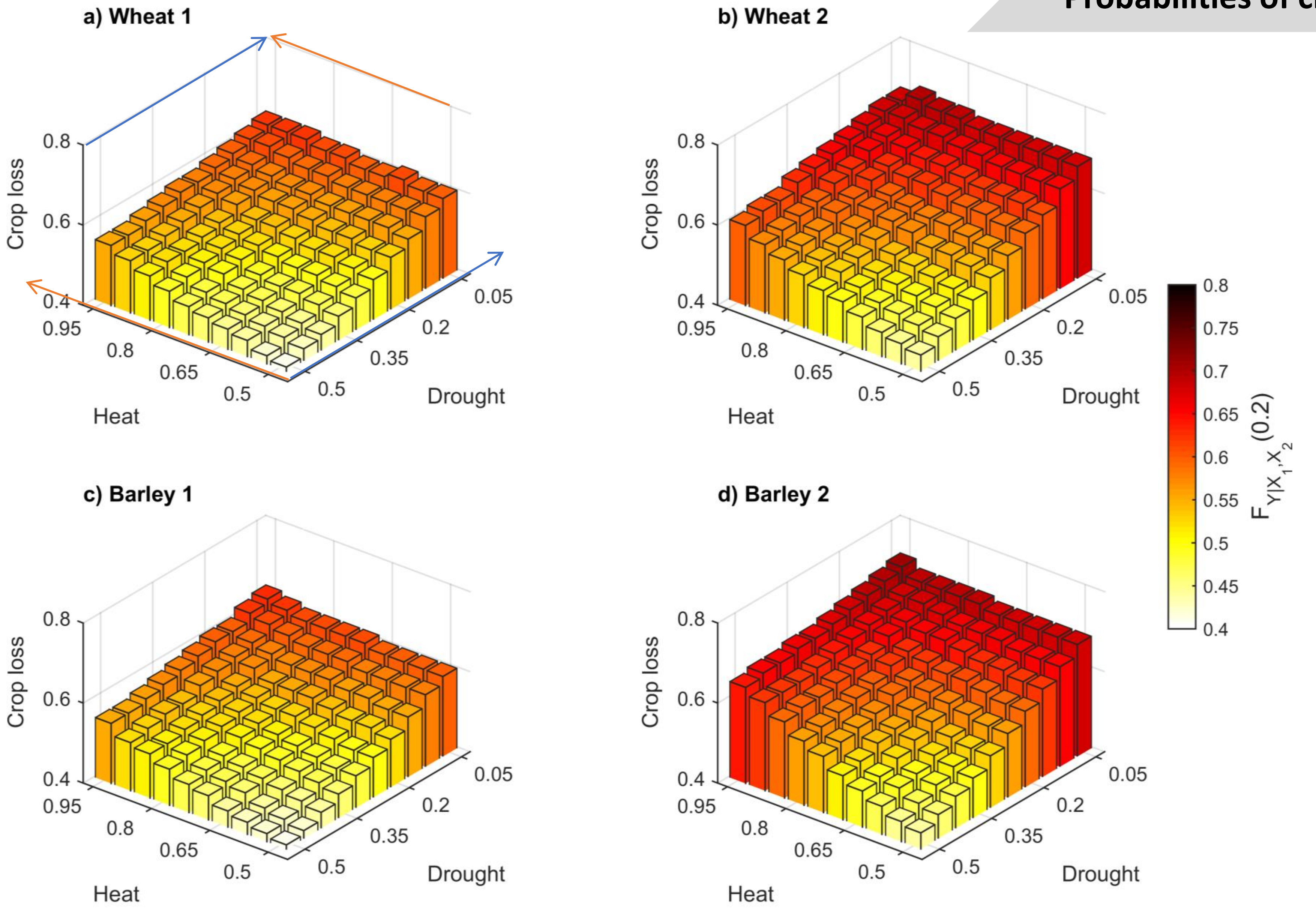
Probabilities of crop-loss under dry&hot conditions



- **Crop-loss increases with the severity of the compound event**

Results

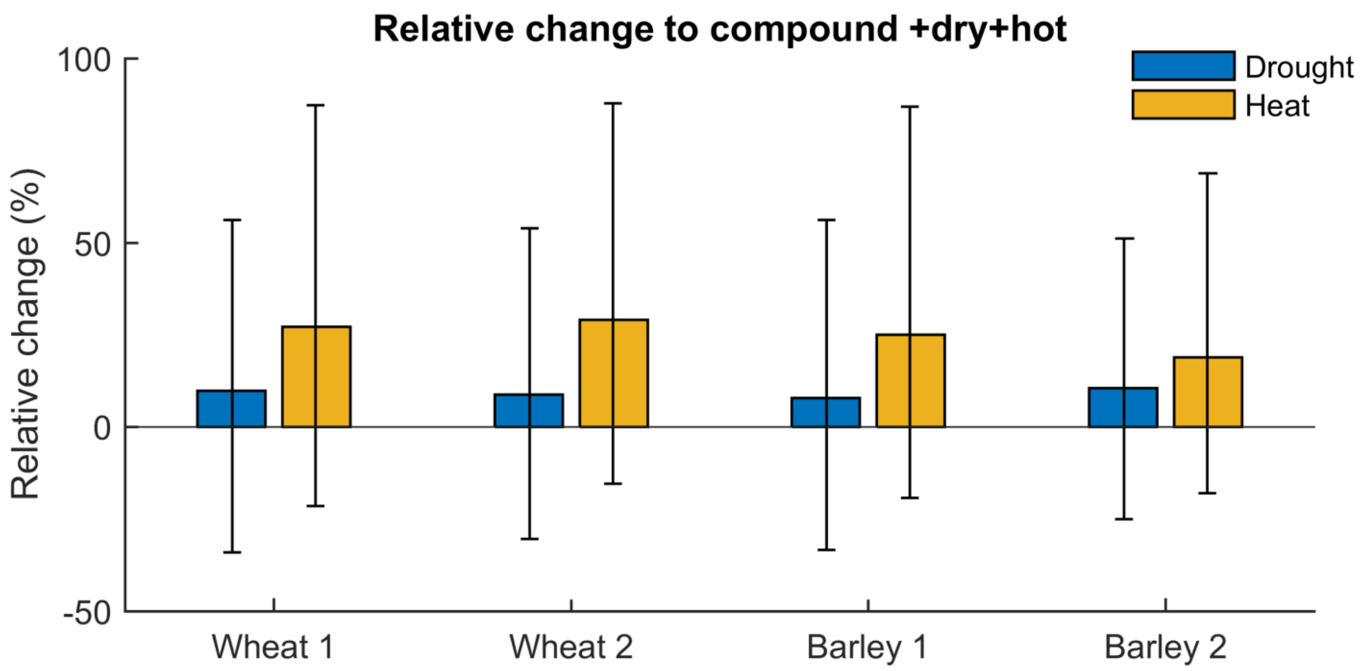
Probabilities of crop-loss under dry&hot conditions



- **Generally, crop-loss due to compound event increases with the severity of the individual hazards**
- **Generally, the probabilities of crop-loss are slightly higher in cluster 2**

Results

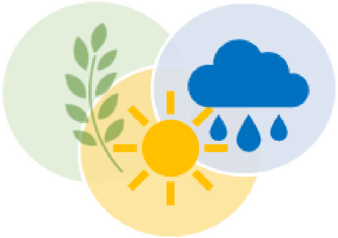
Compare dry and hot with dry&hot



Relative changes in crop-loss from dry (blue) or hot (yellow) influence to compound hot and dry condition (relative change from drought stress (%) $= \frac{F_{1|2,3}(0.2) - F_{1|2}(0.2)}{F_{1|2}(0.2)} \times 100$ and relative change from heat stress (%) $= \frac{F_{1|2,3}(0.2) - F_{1|3}(0.2)}{F_{1|3}(0.2)} \times 100$).

- **Changes from hot stress to compound event are higher than changes from drought stress**
- **Drought is the major contributor for the crop-losses associated with the compound event**

Summary



- A dependence between yield, drought and hot conditions is suggested based on archimedean nested copulas
- The probability of **crop-loss increases with the severity of the compound event**
- Drought plays the major role in crop-loss due to compound event
- The likelihood of crop-loss is slightly higher in the southern region

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Risk of crop failure due to compound dry and hot extremes estimated with nested copulas

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