Risk of crop-failure due to compound hot and dry extremes in the Iberian Peninsula

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1. Motivation

Drought and heat events are a stress factor to agricultural systems and may threaten food security **[1]**.
Compound drought and heat events are assessed regarding how much they enhance crop (wheat and barley) losses in comparison with the individual hazards.
This work will contribute to design supporting tools and provide guidance in the decision-making process in agricultural practices to minimize crop losses related to climate hazards.

2. Data

Spring maximum temperature ($Tmax_{MAM}$), spring precipitation (P_{MAM}) and wheat and barley yields were considered for two province clusters in Spain dominated by rainfed agriculture (**Fig. 1**). The climate variables and averaging periods have been chosen to maximize the dependence between climate conditions and yields **[2]**.

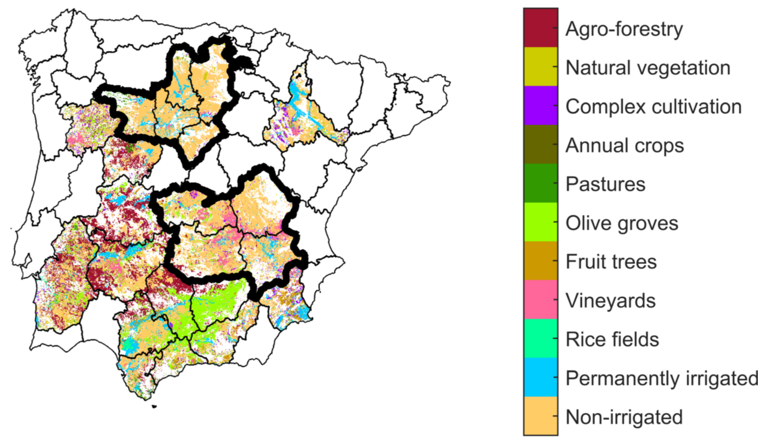

Fig. 1 – Provinces dominated by agriculture and respective land cover categories. The contiguous provinces dominated by rainfed practices are delineated in bold black contours and grouped in two clusters.

We considered the 20th percentile of the crop anomaly time-series as lower exceedance threshold for crop failure (**Fig. 3** a) - d) black dashed line) and three severity levels of dry and/or hot conditions: Moderate (+), Severe (++) and Extreme (+++) based on percentile thresholds (**Table 1**).

Table 1. Categories of severity levels of dry and hot conditions.

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

3. Statistical methods

The three conditional cumulative distribution functions (CDFs) are estimated and compared, representing the agricultural impacts under dry (**Eq. 1**), hot (**Eq. 2**) and compound dry and hot conditions (**Eq. 3**):

$$F_{Y|X_1}(Y|X_1 = x_1^*) = P(Y \le y|X_1 \le x_1^*) \quad \text{(Eq. 1)}$$
$$F_{Y|X_2}(Y|X_2 = x_2^*) = P(Y \le y|X_2 \le x_2^*) \quad \text{(Eq. 2)}$$
$$F_{Y|X_1,X_2}(Y|X_1 = x_1^*, X_2 = x_2^*) = P(Y \le y|X_1 \le x_1^*, X_2 \le x_2^*) \quad \text{(Eq. 3)}$$

Where Y=crop yield annual anomalies, $X_1=P_{MAM}$, $X_2=Tmax_{MAM}$, x_1^* and x_2^* the dry and hot thresholds (**Table 1**).

Copula theory **[3,4,5]** was used to model the trivariate dependence between $Tmax_{MAM}$, P_{MAM} and wheat and barley yields using Nested Archimedean Copulas (NAC) **[6]**, where two of the margins are coupled by their bivariate copula:

$$C(u_1, u_2, u_3) = C_1(C_{12}(u_1, u_2; \theta_{12}), u_3; \theta_1) \quad \text{(Eq. 4)}$$

Once the best NAC model is known, uniformly distributed data is sampled allowing the estimation of **Eq. 1-3**.

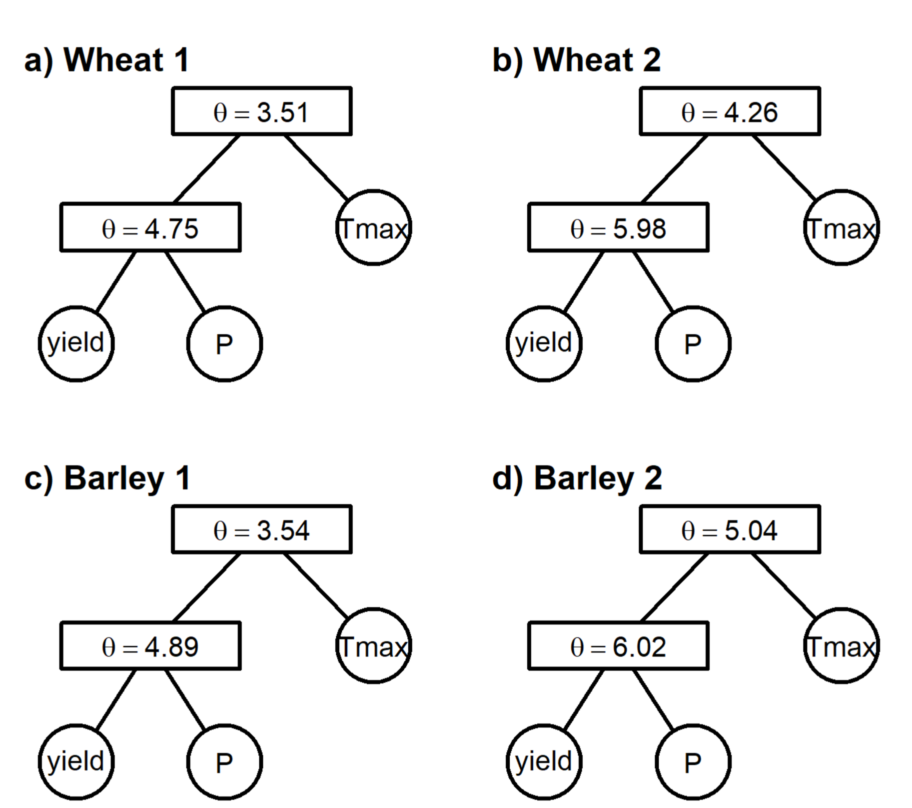

Fig. 2 – Structure and respective parameters of the NAC Frank models $C_1(C_{12}(u_1, u_2; \theta_{12}), u_3; \theta_1)$ to model the trivariate joint distributions between crop yields, P_{MAM} and $Tmax_{MAM}$.

In both cereals and clusters the most dependent pair of variables corresponds to crop yields and P_{MAM}.

In all cases, the NAC models with Frank copulas provides the best fit (Fig. 2).

4. Results

Crop loss increases with the severity of the compound event in both clusters and cereals (**Fig. 3**).

Higher chances of crop loss in cluster 2 (**Fig. 3 and 4**) namely for barley.

Crop loss due to compound dry and hot conditions is driven primarily by drought than by heat, suggesting that drought causes more damage to crop yields than heat stress, even for lower values of stress (**Fig. 4**).

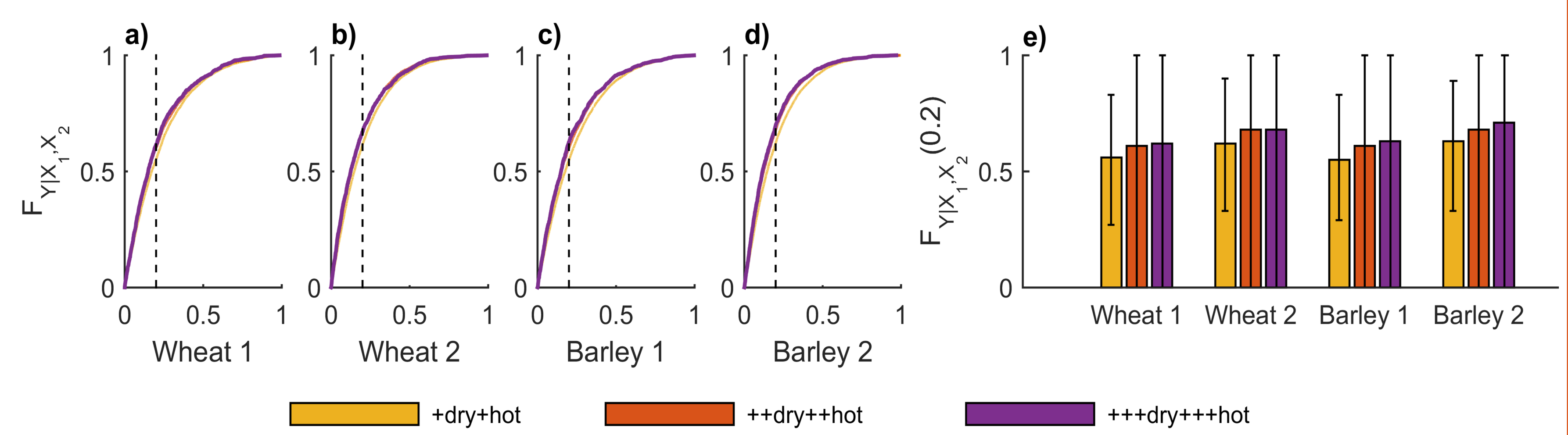

Fig. 3 – a) – d) Conditional probability distributions of crop yield anomalies over each cluster under moderate, severe and extreme dry and hot conditions. e) Bar heights indicate conditional probabilities of non-exceeding the crop-loss threshold (20th percentile, vertical black dashed line a)-d)). Uncertainty ranges illustrates the 95% confidence interval.

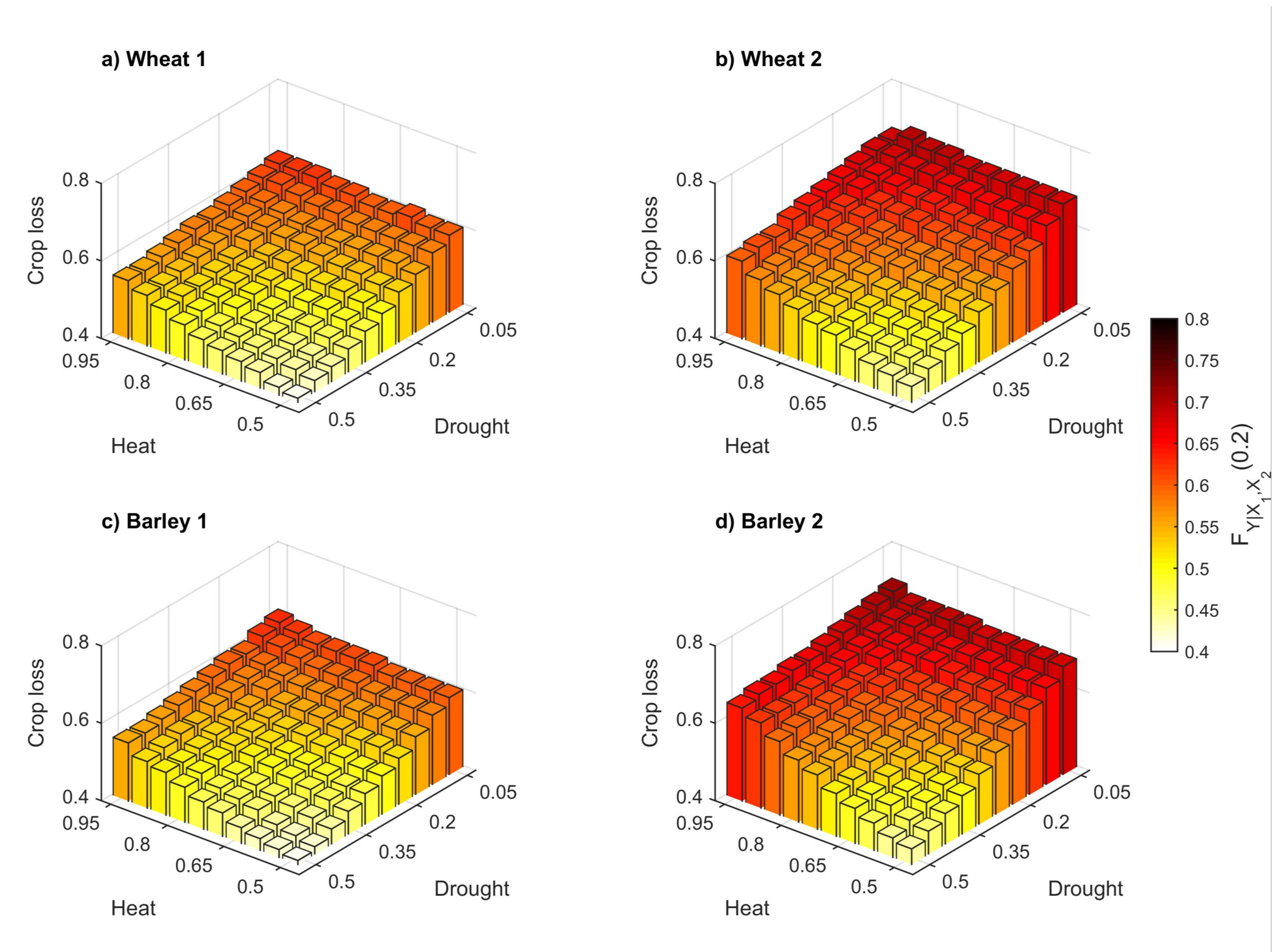

Fig. 4 – Conditional probabilities of crop loss (bar height) for different combinations of severity levels of dry and hot conditions starting from the 50th percentile of $Tmax_{MAM}$ and P_{MAM}.

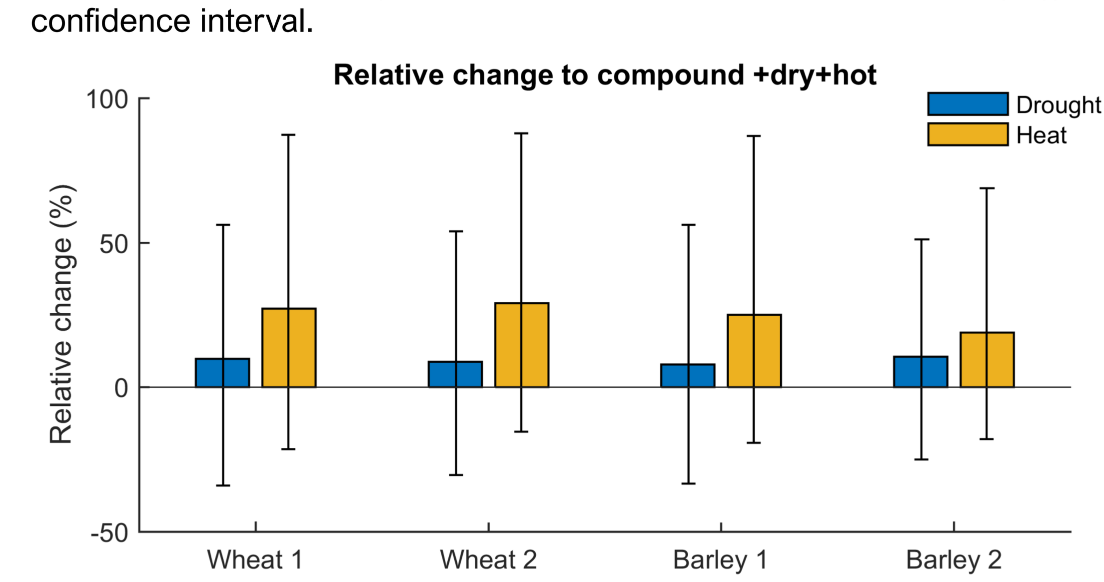

Fig. 5 – Difference in probability of crop loss from dry and hot to compound dry and hot conditions. Shown are the best estimates for moderate conditions (bar height) and associated 95% confidence intervals.

The additional effect of compound dry and hot conditions is larger when starting from only hot conditions, compared to when starting from only dry conditions suggesting that drought plays a dominant role in the compound event (**Fig. 5**).

5. Conclusions

- A dependence between crop yield, drought and hot conditions is suggested based on Nested Archimedean Copulas (NAC)
- The probability of crop-loss increases with the severity of the compound event and increases when drought or heat aggravate to compound dry and hot conditions in both regions and cereals
- Drought plays the major role in crop loss due to compound event
- The likelihood of crop-loss is slightly higher in the southern cluster for both cereals, particularly in the case of barley

REFERENCES

A preprint of this results is currently under review https://doi.org/10.5194/bg-2020-116

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