Title: Spatiotemporal variation of growth-stage specific concurrent climate extremes and their yield impacts for rice in southern China

Response to Reviewer Comments (RC2):

'Comment on egusphere-2025-1393', Anonymous Referee #2, 03 Jun 2025

The paper has significantly improved compared to the earlier version. I thank the authors for taking the revision process seriously and applying the requested modifications.

In my view, the paper still requires more clarifications, particularly in the methods section and in how the results are contextualized within the broader literature:

RE: Thank you so much for your comments and suggestions on our manuscript. We will try to clarify the points that you have mentioned to improve the manuscript further. We have responded to the comments and suggestions point-by-point below (in blue).

Major Comments:

RC2.1.1 Copulas are introduced but never mentioned in the results. Is the KDE introduced in Fig. 2 equivalent to the copula CDF? If so, the terminology needs to be harmonized. If the KDE represents something else, this should be clearly introduced in the methods section.

RE: Sorry for the confusing results. KDE is NOT equivalent to the copula CDF. The KDE figure tried to present the density of event occurrence along the time. As it confused both reviewers, we have decided to remove the KDE parts.

We offered the copula CDF results here for your reference. In the previous manuscript, copula CDF results were not presented directly, but the inverse-transformed exceedance probability of compound severity, derived directly from the copula CDF (Figure R1) of simultaneous exceedances of both climate variables above their growth-stage thresholds. These results were shown in Figure 2 (b, d), Figure 3, and Figure 5, where each map and time series embody the joint probability computed by the copula, converted to a standardized severity index via the inverse normal transform. However, per your suggestion, we have decided to supply copula CDF results in the supplementary material, so that readers could access the dependence pattern between each pair of two stress.

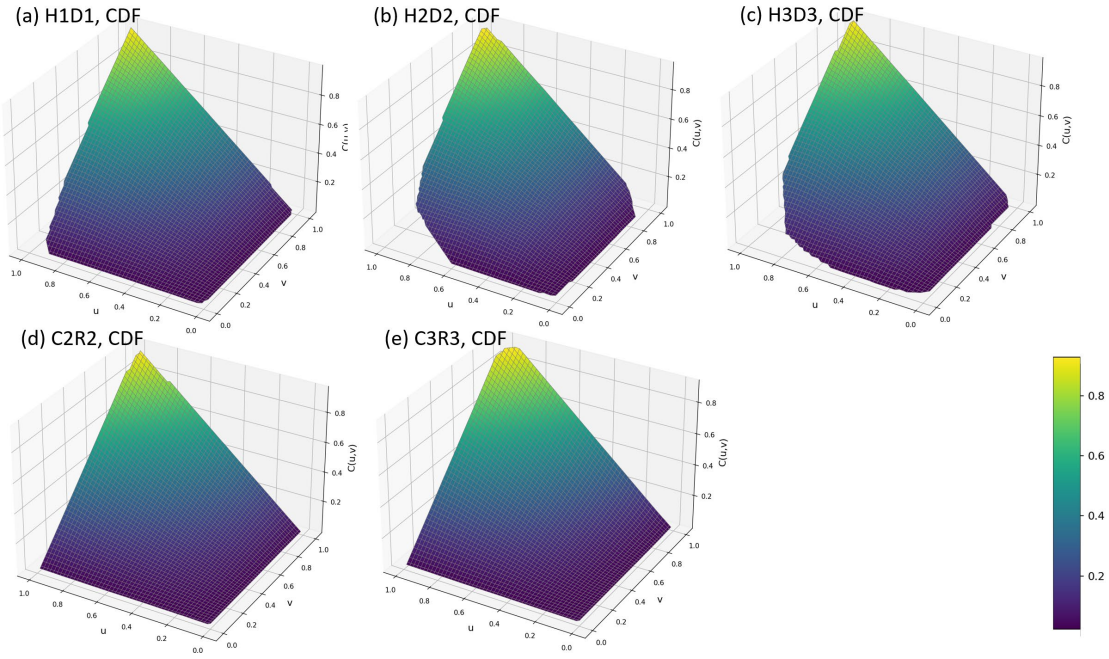

Figure R1. Copula cumulative distribution functions as 3D surface of u (heat severity) and v (drought severity) for concurrent heat-drought events during jointing-booting#1 (a, H1D1); heading-flowering#2 (b, H2D2); grain filling stages#3 (c, H3D3) and concurrent chilling-rainy events during heading-flowering#2 (d, C2R2); grain filling stages#3 (e, C3R3).

RC2.1.2 In the copula section, the purpose of Lines 204–207 and Equation 6 is unclear. Isn't the joint probability (i.e., P(x > X, y > Y)) the main quantity of interest? If so, why not introduce Equation 7 directly? You may refer to this article for inspiration on copula methods and joint return periods: https://wires.onlinelibrary.wiley.com/doi/10.1002/wat2.1579.

RE: Thank you! Yes, the joint probability of (i.e., $P(X \leq x, Y \leq y)$) is the main quantity of interest. But due to our definition of severity for each individual stress, we have slightly modified the conventional formula to adapt to our case.

In our copula framework, Equation 5 implements the base copula function $C(u, v)$ as in the referenced literature's Equations 2 and 3 (Tootoonchi et al., 2022).

$$P(X \leq x, Y \leq y) = C[F(X), G(Y)] = C(u, v) \quad (5)$$

In which u and v are the severity of individual stress, i.e. S_{H1} and S_{D1} for heat and drought in the joint-booting stage. According to our definition, our severity scores have many "0" values as in years that the threshold is not surpassed. Therefore, in the fitting process, samples that u=0 or v=0 were not included, and should be taken back into account when we derive the joint exceedance probability.

As our main quantity of interest is the joint exceedance probability $P(X > x, Y > y)$, we applied Equation 6:

$$P_{S_{H1}S_{D1}} = P(S_{H1} \geq x, S_{D1} \geq y | x > 0, y > 0) \cdot P(x > 0, y > 0) = [1 - u - v + C_{H1D1}(u, v)] \cdot \frac{n(x>0, y>0)}{N} \quad (6)$$

Two calculations were included in this equation. We firstly converted exceedance probability by using

formula: $P(X > x, Y > y) = 1 - u - v + C_{H1D1}(u, v)$, where u and v are the marginal CDF values for each severity. Besides, we also applied the law of total probability through the conditional probability framework by multiplying the conditional exceedance probability $P(A|B)$ by the marginal event probability $P(B)$, yielding the overall joint probability $P(A)$. This transformation will get the years without compound events (either u=0 or v=0, not fitted in Equation (5)) back into account when computing the joint exceedance probability.

Finally, Equation 7 translates that joint probability into a severity index via the inverse transform, so that lower z-scores correspond to more severe compound extremes.

$$CS_{H1D1} = \varphi^{-1}[P_{S_{H_1}S_{D_1}}] \quad (7)$$

In the revision, we plan to expand Section 2.4 to clarify above issues, and to elaborate from raw copula CDF to joint exceedance probability, and then to normalized severity scores, with citations to (Li et al., 2022; Wu et al., 2021) and related copula literature.

RC 2.2 Section 2.6 is rather generic. What are B1 and B2? Please introduce them properly. If B1 refers to climatic conditions and B2 to non-climatic factors, then from Line 416 onwards, a direct inference about the impact of infrastructure on yields cannot be made.

RE: Thank you for your question. Equation (9) is used to detrend historical yield time series to derive standardized yield anomalies, following the (Ye et al., 2015). In the equation, β_0 is the intercept, and β_1 is the slope of the regression line. β_1 captures the long-term exponential trend in yield improvement for which the literature generally assumes as technological trend (Holly Wang & Zhang, 2003). This formulation does not explicitly decompose climatic (β_0) and non-climatic (β_1) components.

Give above confusing situation, we plan to revise the text to clarify this equation, and its coefficients. The sentence from Line 416 and any related interpretation regarding non-climatic drivers like infrastructure will be removed to avoid unsupported inferences.

RC 2.3 Discussion section: Please revise the text to reflect the broader implications of your findings and include only points that can be directly deduced from your analysis.

RE: Thank you for your guidance on tightening the Discussion. Our broader implication is of two folds: (1) While our study focuses on rice in southern China, the analytical framework is not crop- or region-specific, and may be applied to other major staple crops and agro-ecological zones; (2) The findings offer practical insights for managing compound extreme events in rice production systems in southern China. Speculative or unrelated content will be removed to ensure a clear and evidence-based narrative.

RC 2.4 Specific Comments:

L14: "Hamper" doesn't sound right.

RE: Thank you for the suggestion. We plan to replace it with "limit".

L116: Briefly introduce the two datasets at the end of this sentence before discussing them individually.

RE: Thank you for the suggestion. To improve flow, we will spell out the two datasets at the end of the first sentence: "We used two complementary rice phenology datasets: rice agrometeorological station observations dataset (1981–2018) (CMA, http://data.cma.cn) and the ChinaCropPhen1km dataset (2000-2019) (Luo et al., 2020)".

L121 (and repeated elsewhere, e.g., L163): What is "QX/T 468–2018"? This terminology is unclear. If it refers to internal coding, it may be unnecessary to mention.

RE: Thank you for the suggestion. "QX/T 468–2018" stands for Standard ("T") in the Meteorological Administration (QX stands for QiXiang, which is the Chinese pronunciation of Meteorology). "QX/T 468–2018" represents "Specifications for agrometeorological observation-Rice". We will explain the term and provide necessary information in the revision.

L248: Use "The impact of … on yield" instead of "yield impact."

RE: Thank you. We will revise as suggested.

Figure 4: I am not sure I understand what DC refers to. If it represents correlation, shouldn't the boxplot range be limited to 1? Why does it go up to 1.2 in panel d1 C2r2 for DCtot?

RE: In the path analyses, DC denotes the coefficient of determination derived from squared path coefficients ($DC_i = P_i^2$) and that the co-determination coefficient (DC_{co}) arises from the interaction term ($2P_i r_{ij} P_j$). Summing all direct and co-determination terms can yield a total DC_{total} greater than 1, reflecting the combined explanatory power of individual and interactive effects. We will explicitly explain this so that readers understand why values may exceed unity. We will clarify in the revised Methods and figure caption.

L384–396: This section needs thorough revision. The reference to Zhang is problematic. Additionally, suggesting a dominant factor may not be valid, as these relationships are likely highly location- and case-specific. "Large" is not the right word here. Please remind the reader what "#3" refers to.

RE: Thank you so much for the suggestion. We will rewrite lines 384–396 to remove the problematic Zhang citation, avoid implying any universally dominant driver, and replace "large" with more precise descriptors. We will also clarify that "#3" refers to the grain-filling stage. The revised text will focus strictly on our own stage-specific findings without overgeneralization.

L417: Use "Different impacts of … on yields" instead of "yield impacts."

RE: Thank you. We will revise as suggested.

L421: Were these losses shown in any figures or derived from your analysis? If not, consider removing this sentence. Also, since the study does not directly assess the impact of irrigation, that discussion may not be relevant.

RE: Thank you. The losses don't come from my results. We will delete this sentence and the related discussion of irrigation, ensuring our narrative remains confined to results derived directly from our analysis.

L437: Replace "rainy stress" with "rain stress."

RE: Thank you. We will revise as suggested.

L456: On what plots are these spatial shifts in concurrent events shown? If you refer to shifts over time, clarify this. If not, the sentence is unclear.

RE: We acknowledge the confusion. The term "shifted" misleadingly suggests a temporal change; in fact, we intended only to describe the changes in the compound heat-drought hotspots by rice growth stage. We will rephrase this passage (in both the main text and abstract) to clearly convey that these are spatial distribution characteristics, not temporal shifts.

L457: "Spatial difference in phenology" is unclear, please rephrase.

RE: We will rephrase this sentence to: "These spatial patterns are driven primarily by differences in crop phenology across locations—such as the timing of flowering in early versus late rice, rather than by the spatial distribution of extreme climate conditions."

L463 onwards (Conclusion): The conclusion is not the right place to introduce new references or discuss limitations. Consider revising this section and relocating these points to more appropriate sections in the manuscript.

RE: We will confine the Conclusion to summarizing key findings already presented and remove any newly cited literature or discussions of limitations. All material on study constraints and future directions will be moved to the Discussion or Methods as appropriate.

References:

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