

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

**Response to Reviewer Comments (RC1):**

**'Comment on egusphere-2025-1393', Anonymous Referee #1, 20 May 2025**

The manuscript presents a well-designed and timely study on the correlation between compound climate extremes and rice yields in southern China, with clear relevance to climate change adaptation. The authors leverage growth-stage-specific physiological thresholds, multi-source gridded data, and compound severity metrics to offer new insights into how concurrent heat-drought and chilling-rainy events affect rice production. This work makes an important contribution in the construction of metrics for compound stressors. However, several points require clarification, and improvements in structure and presentation would significantly improve the manuscript.

**RE:** Thank you so much for your comments and suggestions on our manuscript. We have responded to the comments and suggestions point-by-point below (in blue).

**Major Comments:**

**RC1.1** Ambiguity in Drought Stress Severity Definition. The calculation of drought severity appears to exclude events shorter than 10 days, regardless of intensity. Please clarify whether severity is accumulated continuously or only calculated if a 10-day event threshold is met. For rice, a very low soil moisture period, even for a week, can be fatal. Justification for this duration cutoff should be provided, ideally based on physiological or agronomic evidence.

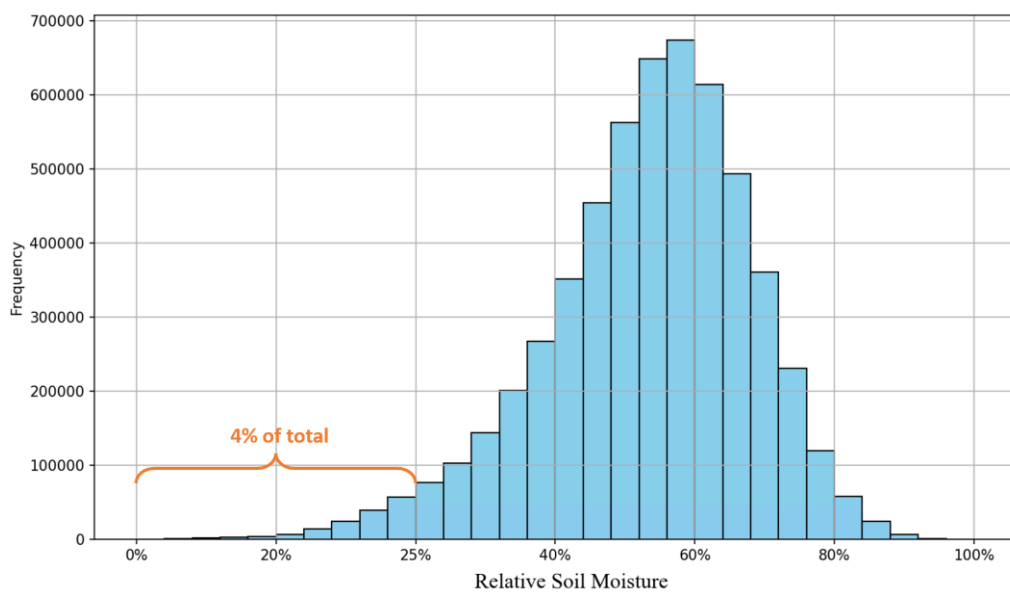
**RE:** Thank you for the question. The calculation of drought severity accumulates from Day 1 (the onset of soil moisture falling below the defined threshold). However, we retain and analyze only events persisting for  $\geq 10$  consecutive days. The threshold of ten days was applied based on physiological and agronomic relevance and experimental evidence.

Drought development in field environments (especially paddies) is gradual (Perdomo et al., 2015), hence in the existing literature, experiments usually adopts relatively long duration for drought stress. For instance, in a study evaluating drought stress effects on growth, yield, and physiological activities of rice varieties, the drought treatment duration was set to 14 days (Amin et al., 2022). A field investigation assessing seven rice cultivars under continuous irrigation regimes established drought exposures averaging 60 days to examine yield potential under water stress (Barnaby et al., 2019). Research on high temperature and water stress impacts during heading and grain filling stages implemented targeted 10-day drought

treatments at heading phase to analyze pollen development and grain quality (Duan et al., 2012). An evaluation of long-term combined heat and water deficit stress on global crops imposed minimum 40-day drought treatments to quantify impacts on plant growth and water-use efficiency (Perdomo et al., 2015). What's more, the long-term stress (>20d) alters growth and water-use efficiency, no evidence confirms significant yield reduction from short-term stress (Costa et al., 2021).

The impact of short-duration drought on rice remains debated. While extremely severe but brief droughts can be fatal, in some cases, rewatering after short-term stress can promote growth and increase biomass. During vegetative stages, drought enhances soil aeration and root-shoot ratio, improving nutrient/water uptake without compromising growth; while in reproductive stages, short-term drought triggers compensatory recovery post-stress, potentially accelerating grain filling without yield loss (Chi et al., 2001; Jiang et al., 2019; Li et al., 2005). To minimize the influence of these uncertain effects, we set a 10-day threshold to exclude short-duration drought events.

According to China's national standard for agricultural drought classification (Grade of agricultural drought-GB/T 32136-2015), relative soil moisture below 25% is classified as "extremely severe" drought. We analyzed the histogram of relative soil moisture in our study area and during the phenological stages of interest. The results showed that extremely severe drought events are relatively rare in frequency, with the cumulative frequency of single-day relative soil moisture  $\leq 25\%$  accounting for only 4% of the total histogram frequency (Figure R1). Therefore, we believe that excluding short-period droughts does not overlook a major portion of impactful drought events.



**Figure R1.** Histogram of single-day relative soil moisture during rice phenological stages across all stations. Bars with relative soil moisture  $\leq 25\%$  account for 4% of the total frequency.

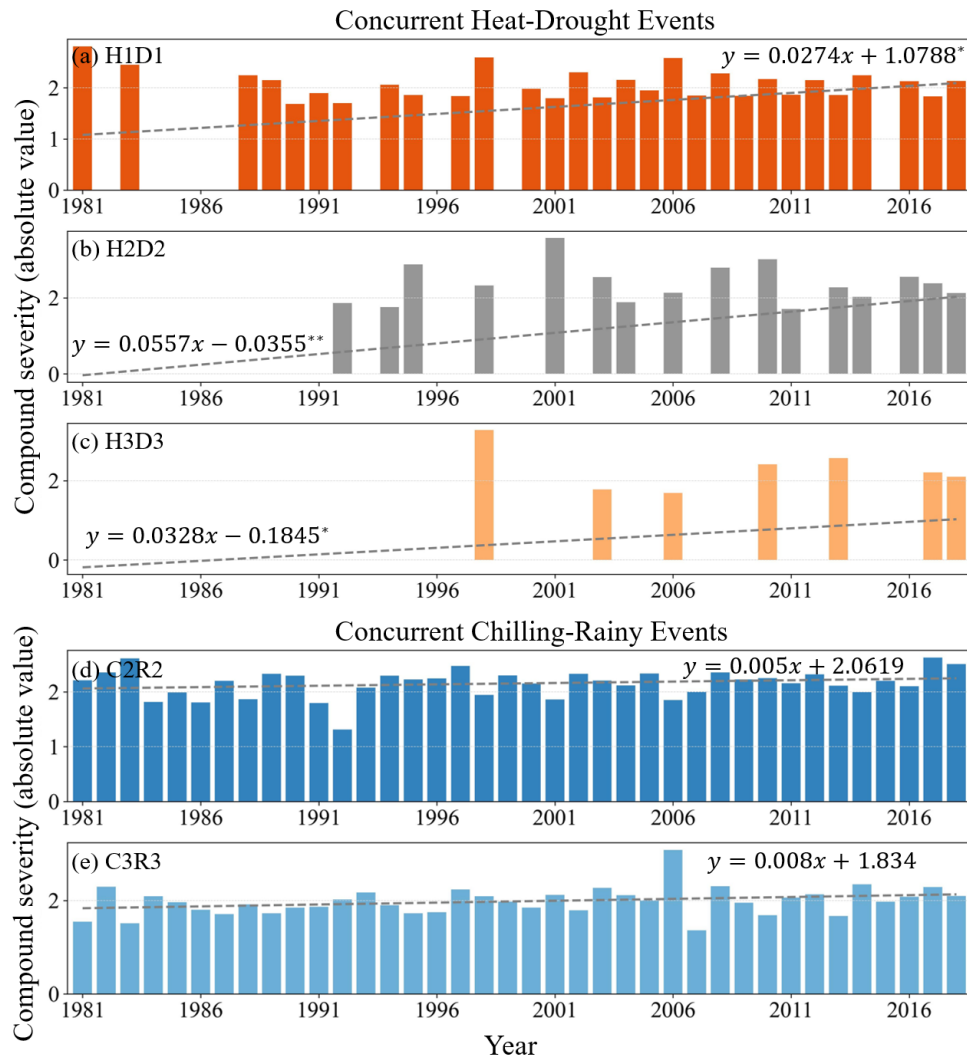
Considering rice's recovery capacity, the hydrological buffering of paddy systems, and the low frequency of extremely severe drought, the 10-day threshold serves to filter out transient fluctuations while retaining events that pose a high risk of physiological disruption. We have incorporated this rationale, along with the explanation of the threshold-based continuous accumulation method, into the revised Methods section of the manuscript, please refer to Lines 178-185.

**RC1.2** Clarification of Kernel Density Estimate. Figures 2a and 2c are labeled as Kernel Density Estimates (KDEs), but the x-axis represents time (e.g., 1981–2018), which is not standard in KDE applications. It is confusing what variable is being smoothed, and how the density values should be interpreted. If these are smoothed frequencies or rolling densities over time, the figure should be relabeled or revised accordingly. I recommend providing a more detailed explanation of the construction, including the variable used, kernel type, bandwidth selection, and the interpretation of density on a time axis.

**RE:** Sorry for the confusion caused by the Figures 2a and 2c. After careful reconsideration, we have decided to remove all KDE visualizations (Figs 2a/c). Instead, we have created separate bar plots for heat-drought (H1D1/H2D2/H3D3) and chilling-rain (C2R2/C3R3) events (Figure R2). We have updated relevant figure and results in the manuscript (Section 3.1, Lines 298-313).

We recognized a fundamental methodological mismatch in our initial approach. Applying KDEs directly to event occurrence years resulted in counterintuitive density interpretations along the time axis, as rightly highlighted by the reviewer. In addition, stacking multiple KDEs failed to resolve core visualization challenges. In our original construction:

- Variable Smoothed is the occurrence years of compound events (i.e., each year was a data point).
- Kernel Type: We used a Gaussian kernel.
- Bandwidth Selection: Bandwidth was selected automatically using Silverman's rule of thumb.
- Interpretation on Time Axis: The resulting density curve represented the \*estimated probability density function of event occurrence across the years (1981-2018). Peaks indicated years with a higher relative concentration (density) of events, not higher frequency counts.



**Figure R2. Annual compound severity of concurrent compound events during 1981–2018.** Panels (a–c) show the concurrent heat–drought events in single–rice during jointing–booting#1 (H1D1), heading–flowering#2 (H2D2), grain filling stages#3 (H3D3). Panels (d–e) show the concurrent chilling–rainy events in late–rice during heading–flowering#2 (C2R2), grain filling stages#3 (C3R3). \* and \*\* indicate statistically significant at the significance levels of 0.05 and 0.01, respectively.

**RC1.3 Interpretation and Modeling.** The analysis relating yield anomalies to compound severity lacks clarity. Both axes in Figure 5 are restricted to negative values, with no explanation for this truncation. Are positive yield deviations and low-stress years excluded? If so, why?

**RE:** We applied the negative-axis constraint for specific reasons, which differ between the X-axis and the Y-axis.

X-axis represents Compound severity, and its truncation stems from intrinsic metric properties.

In our identification of events, we used the cumulative values surpassing certain threshold to compute severity, and applied copula fitting to derive joint exceedance probability density, based on which a standardized z-score were obtained to denote the compound severity. By the definition, if temperature or moisture did not surpass their corresponding thresholds (as specified in Table 1 in the manuscript), severity would be 0. Correspondingly, we will have a truncation on the X-axis. To some extent, applying the threshold will exclude “low”-stress years, but those thresholds were obtained from national or local Standards, based on intensive field experiments.

Y-axis is about standardized Yield anomaly, derived from the detrended historical yield time series. In our previous version, we excluded positive yield anomalies, by assuming that years with compound climate extremes will strongly have negative yield impacts.

This design stems from the intrinsic properties of our metrics, the negative range of compound stress indices exclusively represents high-stress conditions, while negative anomalies directly measure loss magnitude. Positive values (reflecting favorable conditions, management optimizations, or uncaptured factors) were excluded as they represent distinct regimes, which could obscure the visual salience and scientific focus of the stress-loss relationship.

To clarify, we have added corresponding descriptions in the Methods section 2.6 (Lines 295-296), Results section 3.4 (Lines 374-375), and the caption of Figure 5 (Line 393).

**RC1.4** Final Yield Model. Additionally, the use of simple scatterplots without formal statistical modeling is insufficient, given the complexity of the stress indices. I encourage the authors to fit and report a statistical model or clarify the final equation for this analysis to formally characterize the relationship between yield anomalies and compound stress severity. This would substantiate the visual patterns and improve analysis.

**RE:** Thank you! In direct response, we have reported a statistical model or clarify the final equation for this analysis to formally characterize the relationship between yield anomalies and compound stress severity, in both the method and result sections.

In the method section (Lines 289-296), we added following information (simplified here):

To reveal the statistical relationship between yield anomalies ( $YA_t$ ) and compound severity ( $CS$ ), simple linear regression analyses were conducted by using the equation below:

$$YA_t = \beta_0 + \beta_1 * CS + \varepsilon$$

where  $YA_t$  is the standardized yield anomaly (detrended & normalized).  $\beta_0$  is the intercept (expected yield anomaly at zero stress).  $\beta_1$  is the yield loss per unit increase in compound

severity).  $\varepsilon$  is error term.

In the Results section 3.4 (Lines 369-387), we reported the fitting statistics and update the Figure 5 caption (Lines 388-394) to report the fitted lines and the fitting statistics. This formal modeling substantiated the visual patterns and provided quantitative measures of stage-specific sensitivity of rice yield to compound climatic stress.

#### **RC1.5: Comments on Manuscript Structure and Flow**

Table 2 is referenced in the manuscript but not included.

**RE:** Sorry! This is a typo. We have thoroughly rechecked the table labels in the manuscript, and confirmed that they were now correct.

The manuscript is generally well-organized, but there are several ways the narrative can be improved:

Abstract: Consider simplifying and using more intuitive phrasing to improve accessibility to the general scientific audience.

**RE:** We appreciate the suggestion to improve accessibility. We have revised the Abstract (Lines 13-31) to improve clarity and accessibility for a broader scientific readership.

Introduction: The rationale is well-motivated, but some repetition of literature gaps can be consolidated. Move technical details to Methods.

**RE:** We appreciate this point. To enhance clarity and narrative focus, we have simplified repeated discussions on literature gaps in the Introduction by summarizing the literature gaps in a single section (Lines 56–66) and avoiding repeated mentions in other paragraphs (Lines 49–55). Moreover, technical content related to the stress types and their thresholds (Lines 81–89) has been relocated to the Methods section 2.3. These changes helped streamline the Introduction and better emphasize the motivation, context, and scientific gaps addressed in this study.

Methods: While comprehensive, this section is very dense. I suggest creating a labeled subsections on "Compound Severity Metrics" that put together equations and definitions. A flowchart or schematic of the data-processing pipeline would improve readability.

**RE:** Thank you for the valuable suggestions. To enhance readability, the following changes have been implemented:

To improve clarity and avoid excessive density in this section, we have reorganized the content

into two main sections (Lines 147-244): **2.3 Individual Extreme Types and Severity Metrics (Line 147)** and **2.4 Compound Climate Extreme Types and Severity Metrics (Line 191)**. Within each section, we first describe the respective event types and threshold (**2.3.1 Individual Extremes Considered** and **2.4.1 Compound Climate Extreme Types**), followed by a newly added subsection detailing the methods for calculating severity (**2.3.2 Severity Metrics for Individual Events** and **2.4.2 Compound severity metric**).

**Results:** Avoid overuse of code-like labels (C2R2, H3D3) in narrative prose; use descriptive names. Ensure all figures are introduced with clear interpretive framing.

**RE:** We agree that overusing code-like labels can hinder readability. Throughout the Results section (and the rest of the manuscript), labels such as H2D2, C3R3 will be replaced with descriptive names (e.g., "heat-drought events during heading-flowering stage#2 (H2D2)", "chilling-rain events during grain filling stage#3 (C3R3)" (Lines 302-303, 306-307, 320-322, 333-335, 376...). Furthermore, we have carefully reviewed the introduction of all figures. Each figure reference is now preceded by clear interpretive framing that explicitly states the scientific question or key finding the figure addresses (e.g., "Specifically, the annual compound severity for each type of concurrent climate extremes was averaged within each grid cell to identify and map spatial hotspots (Fig. 3)" (Lines 316-317) or "Figure 5 presents the fitted data points and the regression trend lines to visually illustrate the models." (Line 373).

**Figures:** Improve color bar labeling and add interpretive guidance in captions. Figures 3 and 5 in particular would benefit from better explanation of axis ranges and unit meanings.

**RE:** We thank the reviewer for the suggestions to improve figure clarity. We have revised all figures accordingly, particularly Figures 3 and 5, including improved color bar labeling and added interpretive guidance.

Figure 3 revise caption (Lines 327-331):

"Figure 3. Spatial distribution of compound severity for concurrent climate extremes during 1981–2018. Panels (a–c) show concurrent heat–drought events in single–rice during jointing–booting#1 (H1D1), heading–flowering#2 (H2D2), and grain filling stages#3 (H3D3). Panels (d–e) show concurrent chilling–rain events in late–rice during heading–flowering#2 (C2R2), and grain filling stages#3 (C3R3). Shading represents compound severity (unitless index), with darker colors indicating higher stress severity. "

Figure 5 revise caption (Lines 389-392):

"Figure 5. Relationship between compound severity and standardized yield anomaly during

1995–2015. Panels (a–c) show concurrent heat–drought events for single–rice during jointing–booting#1 (H1D1), heading–flowering#2 (H2D2), grain filling stages#3 (H3D3). Panels (d–e) show concurrent chilling–rain events for late–rice during heading–flowering#2 (C2R2), grain filling stages#3 (C3R3). \*\*\* indicates statistically significant at the significance levels of 0.001."

These revised captions provided the necessary context for interpreting the figures, explicitly define the metrics and units, explain the axis ranges (especially for Fig 5), and offer guidance on how to interpret the visualizations.

Discussion: While informative, the discussion can be tightened.

**RE:** We have revised the Discussion section to improve conciseness and focus. Repetitive summaries of Results have been reduced. In particular, section 4.2 (Lines 431-449) and 4.3 (Lines 463-479) have been streamlined to clearly present the key findings, highlight their novelty (especially regarding growth-stage-specific thresholds and impacts), place them in the context of existing literature, and discuss their implications for adaptation and future research in greater depth.

## References:

- Amin, M. W., Aryan, S., Habibi, N., Kakar, K., & Zahid, T. (2022). Elucidation of photosynthesis and yield performance of rice (*Oryza sativa* L.) under drought stress conditions. *Plant Physiology Reports*, 27(1), 143–151. <https://doi.org/10.1007/s40502-021-00613-0>
- Barnaby, J. Y., Rohila, J. S., Henry, C. G., Sicher, R. C., Reddy, V. R., & McClung, A. M. (2019). Physiological and Metabolic Responses of Rice to Reduced Soil Moisture: Relationship of Water Stress Tolerance and Grain Production. *International Journal of Molecular Sciences*, 20(8), Article 8. <https://doi.org/10.3390/ijms20081846>
- Chi D., Wang X., Zhu T., Xia guimin, & Wang wenyan. (2001). Water Saving and High Yield Irrigation Models of Rice and Soil Moisture Potential Control Criteria. *Transactions of the Chinese Society of Agricultural Engineering*, 17(2), 59–64.
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- Duan, H., Tang, Q., Ju, C., Liu, L., & Yang, J. (2012). Effect of High Temperature and Drought on Grain Yield and Quality of Different Rice Varieties During Heading and Early Grain

Filling Periods. *Scientia Agricultura Sinica*, 45(22), 4561–4573.  
<https://doi.org/10.3864/j.issn.0578-1752.2012.22.003>

Jiang, Y., Carrijo, D., Huang, S., Chen, J., Balaine, N., Zhang, W., van Groenigen, K. J., & Linquist, B. (2019). Water management to mitigate the global warming potential of rice systems: A global meta-analysis. *Field Crops Research*, 234, 47–54.  
<https://doi.org/10.1016/j.fcr.2019.02.010>

Li, T., Li, shaohua, & Wang, J. (2005). Effects of water deficiency stress on transport and distribution of <sup>14</sup>C-assimilates in micropropagated apple plants. *Journal of China Agricultural University*, 5, 44–48.

Perdomo, J. A., Conesa, M. À., Medrano, H., Ribas-Carbó, M., & Galmés, J. (2015). Effects of long-term individual and combined water and temperature stress on the growth of rice, wheat and maize: Relationship with morphological and physiological acclimation. *Physiologia Plantarum*, 155(2), Article 2. <https://doi.org/10.1111/ppl.12303>

**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 have clarified 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).

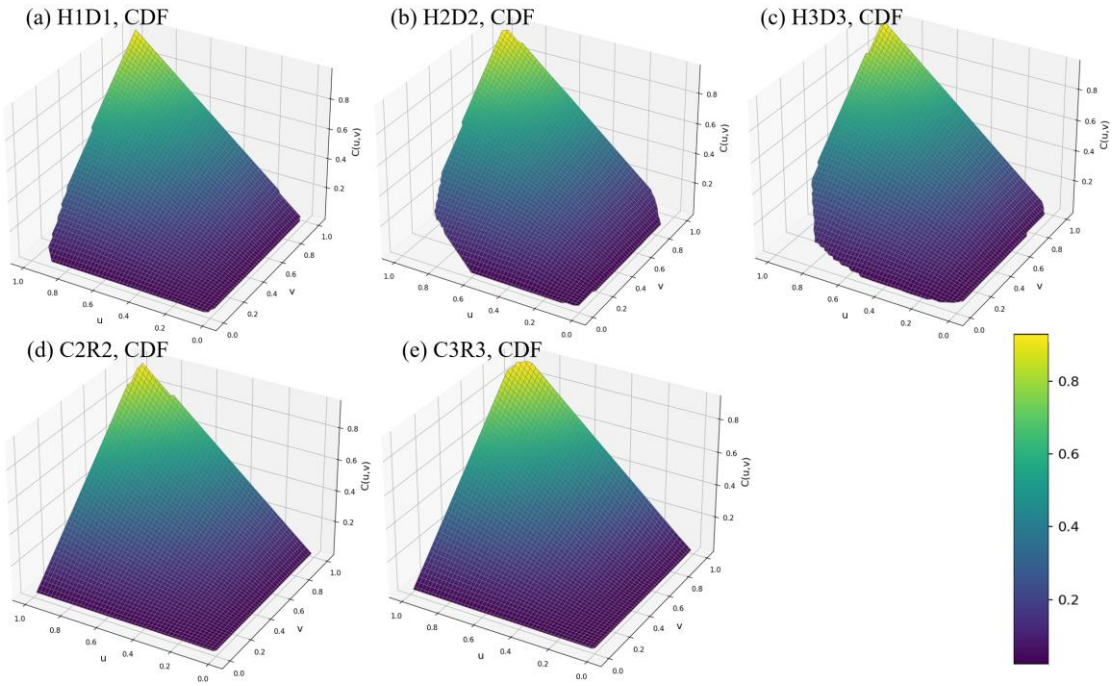
**Major Comments:**

**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

figures tried to present the density of event occurrence along the time. As it has confused both reviewers, we have decided to remove the KDE parts (Line 309).

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. In the revision, we have explained the figure carefully, and supplied the copula CDFs in the Appendix A: Additional Figures section (Fig. A1, Lines 526-530).



**Figure R1.** Copula cumulative distribution functions as 3D surface of  $u$  (heat or chilling severity) and  $v$  (drought or rain 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-rain 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.

$$CS_{H1D1} = \varphi^{-1}[P_{S_{H1}S_{D1}}] \quad (7)$$

We have re-organized section 2.4.2 (Lines 202-244) to clarify above issues, and to provide a detailed explanation of the process, from marginal and joint modeling using copulas to the joint exceedance probability, and then to the normalized severity scores

**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) (revised Eq.10) is used to detrend historical yield time series to derive standardized yield anomalies, following (Ye et al., 2015). In the equation,  $\beta_0$  is the intercept, and  $\beta_1$  is the slope of the regression line.  $\beta_1$  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 ( $\beta_0$ ) and non-climatic ( $\beta_1$ ) components.

Give above confusing situation, we have revised the text to clarify this equation and its coefficients (Lines 276-288). The descriptions in lines 473 and 477 regarding non-climatic drivers (such as infrastructure) were used to explore possible reasons for the severe yield reductions in the Sichuan region and had no relation to Equation 10.

**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.

#### **RC 2.4 Specific Comments:**

L14: "Hamper" doesn't sound right.

**RE:** Thank you for the suggestion. We have replaced it with "limit" (Line 14).

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 have spelt out the two datasets at the end of the first sentence (Line 111-112): "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" developed in 2018. We have removed the code and explained the term, providing necessary information in the revision (Lines 117-118). However, the codes cited in lines 161-164 are publicly available standard numbers. As many similar standards exist, we have retained these codes so that readers can clearly trace the exact standards referenced in our study.

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

**RE:** Thank you. We have revised as suggested (Line 276) and have revised all similar statements throughout the manuscript accordingly (Lines 2, 25, 28, 82, 276, 369, 463, 468, 470, and 500).

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.

In the revision, we have explicitly explained this so that readers understand why values may exceed unity. We have clarified in the revised Methods 2.5 (Lines 265-274) 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 have rewritten this section to remove the problematic citation, and avoided implying any universally dominant driver (Lines 437-449). We have replaced "large" with "sufficiently frequent" (Line 439). We also clarified that "#3" refers to the grain filling stage (Line 447-448). The revised text focused strictly on our own stage-specific findings without overgeneralization.

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

**RE:** Thank you. We have revised as suggested (Line 470).

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

386 **RE:** Thank you. The losses have come from our results and we have rewritten there to clear up  
387 the misunderstanding. (Line 470-471). The descriptions of non-climatic drivers (such as  
388 irrigation infrastructure) were used to explore possible reasons for the severe yield reductions  
389 in the Sichuan region and had no relation to our results.

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

391 **RE:** Thank you. We have revised as suggested (Line 491) and updated this word consistently  
392 throughout the entire manuscript.

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

395 **RE:** on Figure 3. While figures 1, 2 and 3 indicates the sequence of phenological dates of the  
396 first, second and third growth stages. We acknowledge the confusion. The term "shifted"  
397 misleadingly suggests a temporal change; in fact, we intended only to describe the changes in  
398 the compound heat-drought hotspots by rice growth stage. We have rephrased this passage (in  
399 both the main text and abstract, Line 321, 400, 510-511) to clearly convey that these are  
400 spatial distribution characteristics, not temporal shifts.

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

402 **RE:** We have rephrased this sentence to: " These spatial patterns are driven primarily by  
403 differences in crop phenology across locations, such as the timing of flowering was earlier in  
404 the upstream than in the lower Yangtze River basin, rather than by the spatial distribution of  
405 extreme climate conditions." (Lines 511-513)

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

409 **RE:** We have revised the Conclusion section to summarize key findings that have been  
410 presented and removed any newly cited literature or discussions of limitations. All limitations  
411 have been moved (Lines 519-524).

412 **References:**

413 Holly Wang, H., & Zhang, H. (2003). On the Possibility of a Private Crop Insurance Market: A

414 Spatial Statistics Approach. *Journal of Risk and Insurance*, 70(1), 111–124.  
 415 <https://doi.org/10.1111/1539-6975.00051>

416 Li, Z., Liu, W., Ye, T., Chen, S., & Shan, H. (2022). Observed and CMIP6 simulated occurrence  
 417 and intensity of compound agroclimatic extremes over maize harvested areas in China.  
 418 *Weather and Climate Extremes*, 38, 100503. <https://doi.org/10.1016/j.wace.2022.100503>

419 Luo, Y., Zhang, Z., Chen, Y., Li, Z., & Tao, F. (2020). ChinaCropPhen1km: A high-resolution  
 420 crop phenological dataset for three staple crops in China during 2000–2015 based on leaf  
 421 area index (LAI) products. *Earth System Science Data*, 12(1), 197–214.  
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