Title: Spatiotemporal variation of growth-stage specific compound climate extremes for rice in South China: Evidence from concurrent and consecutive compound events

Response to Reviewer Comments (RC2):

'Comment on esd-2024-8', Anonymous Referee #2, 30 Jun 2024

The text is well structured. The flow is generally clear. Considering phonologically relevant growth stages to assess climatic conditions on crops is indeed interesting and adds to the value of paper. However, I have three major comments:

RE: Thank you for your comments and suggestions. We have responded to the comments and suggestions given in the text point-by-point below (in blue).

RC2.1 You have not directly evalauted how/if your climatic indicators actually impact the yields: I would have expected to see some crop simulation with climatic indicators or at least a correlation analysis between crop and climatic conditions. Check following papers to get some inspiration (Luan et al., 2021; Zhu & Troy, 2018; Zscheischler et al., 2017). The way you presented the result in current version, we cannot even be sure even your indicators matter for crops and impact them.

RE: Thank you for your suggestions. We have preliminarily conducted yield impact analyses by using correlation between historical yield and the severity of climatic indicators. Due to the limited time, however, we have not finished all the analyses, but preliminary results on compound chilling-rainy events on late rice are presented here.

Here, we used AsiaRiceYield4km data (Wu et al., 2023) as the yield raster data, covering the period of 1995 to 2015. It is so far the dataset that provides the longest time-series covering whole China rice cultivation areas. Rice yield data with even longer time-series could only rely on the agrometeorological stations, which would again suffer from the sample size issue. To measure the impact, we followed Ye (Ye et al., 2015) by using detrended yield anomaly to remove the spatial difference in yield.

For the intensity of events, we used severity indicators based on suggestion-RC1.4. For chilling, we used the cold-degree-days of the growth stage. The cumulative deficit of average daily temperature (Tmean) $\leqslant$20°C for three or more consecutive days:

$$CDD_{stage} = \sum_{i=1}^{n} |TEM_{base} - TEM_i|$$

CDD_{stage} represents the cold-degree-days for each growth stage. i is the index of the day within the consecutive days that meet the condition. TEM_i is the mean daily temperature value on day i. TEM_{base} is the mean daily temperature threshold (20°C during Heading-flowering stage (stage#2) and 17°C during Grain filling stage (stage#3), according to our threshold

indicated in the manuscript. n is the number of consecutive days that satisfy the condition (at least 3 days).

For the impact of rainy event, we used the cumulative precipitation greater than or equal to 25 mm for three or more consecutive days. A daily 25mm rainfall was classified as the rainy in <QX/T, 468-2018, Code of Agricultural Meteorological Observations-Rice > for precipitation:

$$PDD_{stage} = \sum_{i=1}^{n} |PRE_i - PRE_{base}|$$

PDD_{stage} represents the precipitation-degree-days for each growth stage. i is the index of the day within the consecutive days that meet the condition. PRE_i is the daily precipitation value on day i. PRE_{base} is the daily precipitation threshold (25 mm). n is the number of consecutive days that satisfy the condition (at least 3 days).

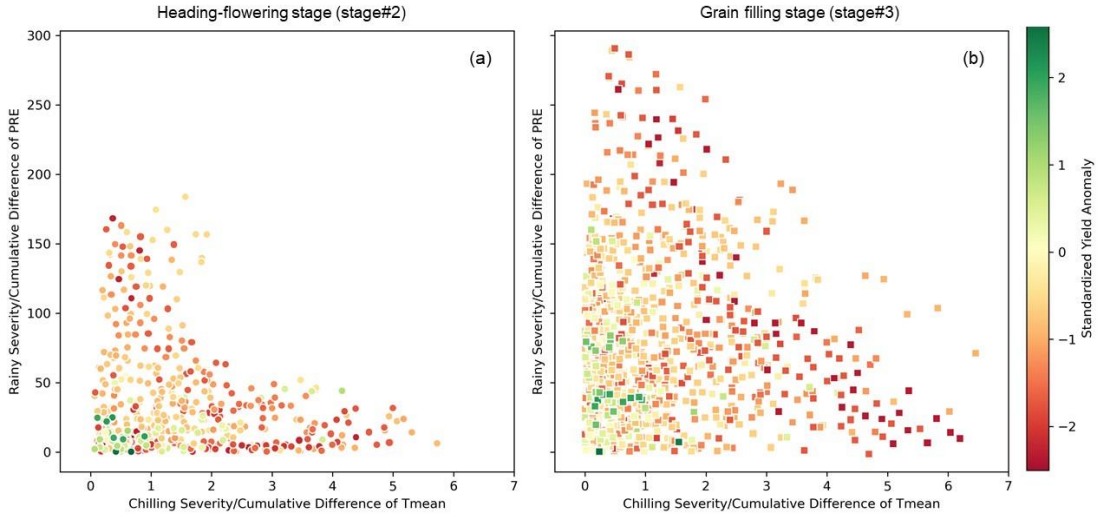

Figure R1. Late-rice yield responses to severity of chilling (temperature) and rainy (precipitation) variation. Color bands indicate the value of the yield anomaly.

Several interesting things could be observed from the figures:

1) There is a clear compound impact of chilling-rainy events on late rice. As severity of chilling or rainy events increased (from the bottom left to the top right of the graphs), yield decreased. The scatters indicate a weakly convex set of isolines, indicating a weakly stronger yield impact than the linear average of single events, that said, the compound impact of having chilling-rainy together would be stronger than the linear combination of the impacts from each stressor.

2) The impact was more severe the Heading-flowering stage (stage#2) than in the Grain filling stage (stage#3), although there were much less compound events in stage #2 than in stage #3 stage. Negative yield anomaly occurred at smaller values of severity in Fig. R1(a) than that in Fig. R1(b).

Due to the limited time of writing up this response, we have not yet finished the rest part of the analyses, i.e. the impact of concurrent heat-drought events on single rice, and the consecutive events.

RC2.2 The text is rather clear when you generally talk about compound heat and drought and the temperature moisturize coupling, in relation to these two indicators. The text, however, becomes vague when you talk about chilling and rain events and how you tried to associate them to some underlying climatic contributor. L174-176 is very unclear and requires further explanation of the method.

RE: Thanks for the suggestion. The major stress of compound chilling-rainy events was chilling (conditions were too cold), and the actual rainfall (conditions were too wet), we therefore used the Pearson correlation coefficient for the relationship between growth-stage mean temperature (T) and s precipitation (PRE) for late-rice $r_{T,PRE}$, over the study period at each station to denote the strength of coupling. Then, we plotted the station-level total duration of compound chilling-rainy events over the study period against its corresponding coupling strength. We have expanded this section in the manuscript.

RC2.3 It is unclear to me why you considered two event types for CSE, according to L152-154. Why two drought or two heat within two growth stage is not considered a consecutive event? In the same lines L153-154 is unclear and requires clarification.

RE: Thank you for your suggestion. Two drought or two heat within two growth stage could also be regarded as a type of consecutive event if we relax the assumption of CSE. In the current version of the manuscript, we excluded such types for two reasons. Firstly, we wanted to link the severity of compound events to the coupling of different climate factors. So at the beginning we requested that the event should consists of two distinct climate factors, i.e. temperature and moisture. Two drought or two heat within two growth stage would be a matter of time-series of moisture, or temperature. Secondly, if we add two droughts or two heats within two growth stage as a consecutive compound event, the types of compound events could be too much complicated. So tentatively we stick to our structure, but will try to analyze the severity, and yield impact of such events.

RC2.4 Specific Comment

Abstract: Consider removing the part talking about maize and wheat. The paper focuses on rice and that needs to be brought up in the abstract.
L62-66: Again consider removing the part talking about wheat and maize, and their growths temperature dependent thresholds. I think they distract the reader.

RE: Thank you for your suggestion. We have removed the parts mentioned by you to keep the manuscript focused.

L93: grain-filling and everywhere when you mention this word: consider removing the dash line between grain and filling. For your other stages the dash bridges two stage but grain filling is a

distinct stage itself.

RE: Thank you! We have revised as suggested, replacing "grain-filling" with "grain filling".

L95: I don't understand why use the term 'dew' sometimes after chilling. Maybe be consistent and use the same terminology or be specific why you need to mention dew in specific parts of the text.

RE: Chilling-dew-wind is a kind of meteorological phenomenon that occurs in the area south of the Yangtze River around the Cold Dew Festival (Oct.8 or 9). Chilling-dew-wind is a cold damage that reduces rice production due to significant cooling caused by cold air invasion in autumn, which is very harmful to crop production. Chilling-dew-wind occurs during the critical period from heading to grain filling of late rice in southern China. For this reason, it is the main agrometeorological disaster in the late growing stage of late-rice production. The term Chilling-dew-wind has a quite Chinese context, but its main way of affecting rice yield is "chilling". So in the rest part of the manuscript, we have used "chilling".

L115: be consistent and use either early rice or single rice. Also, here in L115 it feels like you have three type of rices while I assume there are two rices analyzed in this study.

RE: Thank you. For clarification, we did analyze two types of rice, the single-season rice (single-rice), and the late-season rice (which is second period of the double-season rice, early-rice and late-rice). We will delete "early-rice" at L115 to avoid unnecessary misunderstanding.

Fig 2 &3 : It is unclear to me how you considered total days of compound event. Is it the total during study period? – According to L160-163 they should correspond to yearly values but then did you consider an average of duration per year, over the study period and plotted them in these figures?

RE: Here, the duration of concurrent compound events (CCEs) refers to the number of days when the two hazards occurred simultaneously, and the duration of consecutive compound events (CSEs) refers to the sum of the number of days during which both hazards occurred during the two growth stages. It is the total during each kind of compound events. Our spatial maps (Figure 2 and 3) show the annual summation (1981-2014) of the frequency and duration of each compound event and didn't show the average of duration over each growing stages per year.

Given that both Review #1 (RC1.4) and Review #3 (RC3.3 b) questioned the soundness of the indicator duration, we subsequently used severity instead of duration, according to the definition of Haqiqi (Haqiqi et al., 2021), which would take into account both the duration and intensity of the disasters.

L236: Please clarify where Hunan is located by geographical lat-lon.

RE: The latitude and longitude range of Hunan Province is 24.38-30.08 N, 108.47-114.15 E. The latitude and longitude coordinates of these two stations in Hunan where C2R2 occurs relatively frequently are (28.6 N,112.4 E) and (29.4 N, 112.4 E).

L251-257: I couldn't understand this part. Please consider heavy modification of the text and clarification.

RE: This part focuses on whether when a consecutive compound events (CSEs) event occurs, the temperature and moisture behind that event may also be closely coupled, that is, whether the frequency and duration of CSEs are closely related to temperature-moisture coupling. Our results show that no clear pattern was observed between the occurrence/duration of CSEs and temperature-moisture coupling. So we conclude that there is no potential climate driver behind CSE events.

Fig 4: what is the density in the plots? And what do we learn from it?

RE: Here, the density is the density distribution of temperature-moisture Pearson-rank correlation coefficients. We tried to understand whether there is any connection between the duration of compound events (or its severity) to the growth-stage temperature-moisture coupling (as denoted by their Pearson rank Correlation Coefficients). For instance, for Figure 4(a), the density curve was derived from the correlation coefficients between three growth-stage mean temperature (T) and soil moisture (SM) for single-rice $r_{T,SM}$, over 34 years of 28 single-rice station, and in total there are 28*3=84 samples.

L263: sensitivity of PER to what for late rice? – the sentence is generally unclear.

RE: We think you might have asked PRE(capitation). We took the path coefficient as the relative sensitivity of DUR to T and PRE for late-rice. The absolute values of the path coefficient indicate the extent to which the two elements, temperature and moisture, have an influence in a certain kind of compound event. In addition, we can also see how the effects of temperature and moisture differ in different types of composite events in Figure 5.

L355: consider removing the first line and directly go to the limitations you think the study has.

RE: Thank you! We have revised as suggested.

References:

Haqiqi, I., Grogan, D. S., Hertel, T. W., & Schlenker, W. (2021). Quantifying the impacts of compound extremes on agriculture. Hydrology and Earth System Sciences, 25(2), Article 2. https://doi.org/10.5194/hess-25-551-2021

Wu, H., Zhang, J., Zhang, Z., Han, J., Cao, J., Zhang, L., Luo, Y., Mei, Q., Xu, J., & Tao, F. (2023). AsiaRiceYield4km: Seasonal rice yield in Asia from 1995 to 2015. Earth System Science Data, 15(2), 791–808. https://doi.org/10.5194/essd-15-791-2023

Ye, T., Nie, J., Wang, J., Shi, P., & Wang, Z. (2015). Performance of detrending models of crop yield risk assessment: Evaluation on real and hypothetical yield data. Stochastic Environmental Research and Risk Assessment, 29(1), 109–117. https://doi.org/10.1007/s00477-014-0871-x