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Cover letter for manuscript number EGUSPHERE-2024-2585

Dear Dr. Vico,

We appreciate the continued consideration of our manuscript **"Measuring extremes-driven direct biophysical impacts in agricultural drought damages"**, and the thoughtful feedback provided by the reviewers during this second round of review.

In this revised version, we have addressed the remaining points raised by the reviewers. Specifically, we have clarified the unit of analysis, expanded the discussion of hydro-meteorological extremes beyond drought, and added new supporting material to better reflect the role of multiple extremes in our assessment (including the bar plot in Figure 3 and Supplementary Figure S7). A detailed, point-by-point response to all comments is included.

We sincerely appreciate the thoughtful and constructive feedback provided throughout the review process. We believe the manuscript has been now significantly improved and look forward to your further assessment.

Best regards,
Mansi Nagpal on behalf of all co-authors

Manuscript Number: **egusphere-2024-2585**

Response to Reviewers comments

11 April 2025

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Reviewer comments and authors' replies marked in black

Previous manuscript and supplement text marked in brown

New manuscript and supplement edits marked in blue

All page and line numbers refer to the revised, unmarked manuscript

Response to Reviewer#1

We sincerely thank the reviewer for the positive assessment and constructive feedback. We have carefully addressed the two remaining comments as well as the minor suggestions for clarification, and revised the manuscript accordingly. Our detailed responses to the remaining comments are provided below.

Remaining comments

S.No.	Reviewer's Comment	Authors' Response
1	My first comment relates to the unit of analysis (field, farm, region?) and the aim of the paper (lines 73-75). I still struggle to understand what the aim of the paper is, as it consists of two parts. The first part is about the biophysical damage of extremes and droughts, and the second part relates to farm-level revenue losses. I am a bit confused here, as you work with regional/district-level data and present your results (i.e. Figures 3-7) at a regional level as well. Can you clarify how you measure farm-level revenues with regional data? Or is the unit of analysis regional/district-level? Please check throughout your whole manuscript if it is regional.	Agreed and clarified: We have removed the term "farm" from the aim of the paper to prevent confusion about the unit of analysis. Throughout the manuscript, we now clarify that our analysis is conducted at the district (regional) level. While the term 'farm-level' was based on our conceptualization of the revenue losses, we recognize that this might cause confusion and is not necessary for understanding the paper. All data inputs, simulations, and resulting figures (e.g., revenue losses) are based on district-level aggregations, and this has been made explicit in the revised manuscript. To further improve clarity, we have revised the text surrounding the study's aim in the introduction to explicitly describe the second aim of the paper. Pg 2, lines 73-82: *"The aim of this study is to measure the direct biophysical damage of extreme hydro-meteorological drivers during droughts (hereafter called direct biophysically-induced damages) and assess the contribution of these biophysically-induced damages to the total reported agricultural revenue losses. These damages refer to the loss in revenue caused by the effects of extreme hydro-meteorological drivers on crop yields, without accounting for other economic impacts, such as changes in costs. They include the effects of droughts themselves, as well as additional damage from concurrent or successive weather extremes that exacerbate drought-related effects in regions experiencing drought conditions. To isolate the biophysical impacts of these extremes on crop yields from other influencing factors, we employ crop specific statistical yield models. To evaluate the contribution of these extremes in shaping observed economic outcomes, we compare the direct biophysically-induced damages estimated*

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		from these models with reported revenue losses. This allows to identify the relative contribution of these extremes across different regions and crops, which can guide more targeted drought adaptation and enable better decision-making. *The empirical analysis of direct biophysically-induced damages during droughts is done at the district (regional) level for rainfed agriculture for eight major field crops in Germany from 2016-2022."*
2	My second comment relates to the focus on droughts or droughts and other extreme weather events in the current manuscript. Having read your work again, I have to admit that I still feel the manuscript predominantly focuses on droughts and less on other extremes. You now acknowledge this in the limitations (lines 500-505), where you highlight that these other extremes are not considered in the counterfactual. Besides that, the vast majority of the results focus on droughts. Section 3.4 should be about droughts and other extremes, but I find it still to be dominated by droughts, with little mention of other extremes. Can you describe this a bit better in the main text? Figure 6 is clear, so you could build on that.	Agreed and revised: We have added the clarifying text building on Figure 6 in section 3.4 and discussion section to better highlight the role of extreme events beyond drought in our manuscript. Pg 15, lines 447-451: *"Beyond drought and heat, Figure 6 also highlights the influence of other extreme events on crop yield anomalies in Germany. For example, black frost had notable effects on winter crops in 2021 and 2022 and alternating frost adversely affected rapeseed during these years. In contrast, waterlogging appears to have had a beneficial effect yield anomalies for most crops. These results show the complex interplay of weather extremes and their varying combinations, which determine the extent of yield losses from compounding and overlapping events in different years, as captured by the yield model."* Pg 17, lines 504-506: *"While drought and heat dominate the impacts, the yield model also captures the effects of other extremes—such as frost and waterlogging—whose contributions vary by crop and year."* Additionally, in response to Reviewer#2's comment, we have added a new bar plot in Figure 3, which also helps address this concern by illustrating the relative contribution of both drought and other hydro-meteorological extremes to total biophysical damages. This addition highlights the role of other extremes in our damage assessment.

Minor comments

S.No.	Reviewer's Comment	Authors' Response
1	You often refer to "regions" (e.g. line 187) and sometimes to "districts" (e.g. lines 227-229). Can you define somewhere what you mean by these? Do regions consist of districts (i.e. a region is bigger than a district), or are they synonyms?	Agreed and revised: Thank you for pointing out the inconsistent usage of "regions" and "districts." In our revised manuscript, we have aimed to maintain consistency by referring to them as "districts" and clarifying where necessary that these terms are used interchangeably.
2	Figures 3, 4, and 5: Check the legend and be consistent. Figures 3 and 5 refer to "drought losses," while Figure 4 refers to "drought damages." Should this be consistently "damage"? - Figure 4: "mn" should be "millions."	Agreed and revised: We have revised the figure legends so that all references consistently use "damages," and replaced "mn" with "millions" in Figure 4 for clarity.
3	Lines 395-400: I would refrain from referring to specific districts without specifying where in Germany these districts are located. For non-German readers, that is hard to understand. Specify where Mecklenburg-Vorpommern, Lower Saxony, and Saxony-Anhalt are located.	Agreed and revised: Thank you for highlighting the need to situate these districts for non-German readers. In the revised manuscript, we have added brief geographical references so that readers unfamiliar with German state locations can better understand where these districts lie. Pg 14, lines 419-422: *"Interestingly, in 2019, 2020, and 2022, only limited losses were observed for sugar beets in Mecklenburg-Vorpommern (northeast Germany) and the bordering districts of Lower Saxony (northwest Germany) and Saxony-Anhalt (east-central Germany), despite a considerable share of area in these regions dedicated to growing this crop."*
4	Lines 408-410: "Contrary to intuition,… specific crop affected." Explain what extremes have a positive effect on yield anomalies.	Agreed and clarified: We have included specific examples (precipitation scarcity in March, heavy rain in July) in the revised manuscript to clarify how these extremes may sometimes benefit certain crops. Pg 14, lines 434-437: *"For example, precipitation scarcity in March was found to benefit spring barley, rapeseed, and winter barley if soils still hold sufficient winter moisture (Gömann et al., 2015). Similarly, heavy rainfall in July may increase yields for summer crops such as potatoes and silage maize, by mitigating drought stress in late summer when soils tend to be dryer (Samaniego et al., 2013)."*

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5	Lines 430-435: Thanks for running all these robustness checks and sensitivity analyses. Can you add a couple of lines explaining these findings? What explains the lower and/or upper range? And how do these results increase your confidence in your main model specification?	Agreed and clarified: We have now added explanatory text in section *3.5 "Sensitivity analysis of estimated biophysically-induced direct damages"* clarifying how changes in the counterfactual period or the drought-area threshold affect the expected revenue benchmark, which in turn shifts the damage estimates. We also highlight that, despite these variations, our main results remain within the observed range of outcomes, demonstrating the robustness of our estimations.
6	Lines 506-508: "This study presents a conceptual framework … in agriculture." You just removed the conceptual framework when you revised the paper. Maybe rephrase it to "provides an empirical illustration"? I would also change "economic impacts" to "economic damage" in that sentence to maintain consistency throughout the paper.	Corrected and proofread: Thank you for noting the error. We have removed the mention of the conceptual framework from this sentence and have carefully proofread the text to ensure no such mentions remain.
7	You suggest future research both at the end of the discussion (lines 504-505) and at the end of the conclusions (lines 531-535). I suggest merging these. Either at the end of the discussion or the conclusion is fine.	Agreed and revised: We have merged the text on future research from the discussion with the relevant text in conclusion to maintain consistency.

Response to Reviewer#2

Reviewer's Comment	Authors' Response
I commend the authors for addressing all other major comments, but the issue of damage estimates including more than droughts still remains in my opinion. A simple figure illustrating estimated drought damages during NON DROUGHT years would resolve this. If damage in non drought years is 0, then what is present in the paper should not be changed. If however, the deviations are significant, then drought has either been over or underestimated.	Agreed and clarified: We appreciate the reviewer's continued attention to the accuracy of our damage assessment. We agree that some bias may arise due to the inclusion of multiple hydro-meteorological extremes in the yield model, even in non-drought years, which can slightly influence the estimation of expected revenues. However, we also note that excluding these extremes could underestimate total damages in drought-affected regions, as heat and precipitation scarcity often co-occur with drought and contribute to total damages as shown in the new bar plot introduced in the results section. We now discuss this trade-off in both the results and discussion sections. Specifically, we estimate the relative contribution of drought and other extremes to total biophysical damages (modified

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	figure 3) and assess the potential for bias by examining estimated damages in non-drought affected districts (Supplementary Figure S7). These additions strengthen the contribution of our approach while acknowledging its limitations. Pg 12, lines 364-384: *"These biophysically-induced damages include the effects of all hydro-meteorological extremes, as captured by the LASSO yield models. Because the model accounts for multiple extremes, it is not possible to isolate the effects of drought alone from these damage estimates. To address this, we estimate the relative contribution of individual hydro-meteorological extreme to total damages using the average feature contributions (in percentage) to predicted yield anomalies, based on the models coefficients. These contributions are then used to weight total simulated damages, allowing us to approximate the share of revenue losses linked to individual extremes such as drought (Figure 3b). In years with high damages —2018, 2019 and 2022 —drought accounts for the largest share of total biophysical damages. Notably, heat and precipitation scarcity also contribute substantially during these years. This co-occurrence suggests that these extremes do not act in isolation and most likely interact with each other. For example, heat and precipitation scarcity may exacerbate the impacts of drought by adding further stress on crops or drought conditions may amplify the negative effects of high temperatures or low rainfall. This underscores the importance of including multiple hydro-meteorological extremes in the assessment of damages in drought-affected regions.* *However, it is important to note that our approach also leads to positive values for biophysically-induced damages in districts and years that are not classified as drought (Supplementary Figure S7). This is because the yield model includes multiple extremes, which may still influence the non-drought years used to estimate expected yield and revenue in equation 2. While this may introduce small biases, they are not large in magnitude. Our approach may therefore slightly overestimate damages in*

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	droughts, whereas excluding the effects of other extremes would likely underestimate the total impacts in drought-affected districts and years. The true damages likely fall between these two cases. By including multiple hydro-meteorological extremes, our approach captures the biophysical effects related to extremes more comprehensively in drought affected regions. We further demonstrate the robustness of these estimates through sensitivity analyses that test alternative counterfactual periods and drought classification thresholds in Sect. 3.5." Pg 17, lines 488-492: *"Since the yield model includes all hydro-meteorological extremes, the non-drought years used to estimate expected revenue may still be influenced by these extremes. This can introduce small biases in the damage estimates. To address this, we use a five-year average of non-drought years, which helps smooth fluctuations and reduce the influence of other anomalies. The results are robust to alternative definitions of the counterfactual baseline which supports the reliability of our approach."*