Response to comment of Referee #2

Please find in Black the reviewer's comments and in Blue our responses.

Comment: "**1 General Comments**
The manuscript investigates the link between meteorological drought indicators and drought impacts and, based on that, further attempts to predict drought impacts in a modelling study. While I find the basic idea behind the study intriguing, I think the manuscript is not particularly well executed in terms of structure, logic and intelligibility. It was at times not easy to follow the read thread and to grasp what had been done methodological. But my two main concern relate to the underlying research questions and justifications for this paper as I further explain hereafter in the specific comments. Technical comments and corrections are included further below."

Reply: Dear Claudia Teutschbein, we thank you for your review. We appreciate your time spent and all of your suggestions and critiques. We will address your comments below. Regarding your comment on the execution of the manuscript, we will improve the structure, logic and intelligibility of the manuscript by modifying parts of it according to your suggestions.

Comment: "**2 Specific Comments**
2(a) Link between drought hazard and impacts
"Trying to make a link between meteorological drought and climate indicators (i.e., the hazard) to the actual impacts, which – as the authors themselves state – are "highly dependent on a region's vulnerability to drought" (line 27), without properly discussing the conceptual frameworks for vulnerability and the importance of exposure (the latter term is not once mentioned in the manuscript) is a major flaw in this study. Exposure is related to the tangible entities exposed to the hazard and can be made up of buildings, people, livestock, crops etc. Vulnerability on the other hand, is the susceptibility of a system to be negatively impacted by the hazard. Consequently, impacts will not be reported to EDII just because there has been a drought hazard, but only if a certain region/economic sector or ecosystem has actually been exposed to the hazard and is actually vulnerable."

Reply: We were aware that understanding hazard, exposure and vulnerability are all critical when trying to understand how a region is affected by droughts, but we now realise that we did not discuss the importance of vulnerability and exposure. We will do so in the revised version of the manuscript by adding a paragraph defining and explaining these terms in the introduction and we will also discuss how these factors may play a role in our results.

Comment: "This issue becomes apparent in the results of the study where two of the regions (NE and CE) show lowest correlations with the drought indicators (line 311). When comparing Figure 1 of the manuscript to a population density map of Spain, these two regions clearly are least populated (i.e., less exposure), which might have affected the number of reported impacts."

Figure 1: Comparison of the chosen regions with a population density map of Spain (figure by Dieghernan84, distributed under a Creative Commons Attribution-ShareAlike 4.0 International license)”

Reply: We find the comparison of the regions with the population density map very useful. We will now discuss the importance of exposure, especially in terms of population density, in the discussion. We will mention that the lowest populated regions, which are by definition less exposed, show weaker indicator-impact links in the revised manuscript.

Comment: “To round up, similar attempts have been made by other authors and e.g. Sutanto et al. (2019) particularly suggest to “consider the vulnerabilities and exposure of the impacts in each [...] region, which can provide a good measure for drought impact forecasting”. In addition, Blauhut (2020) states that ”the single use of impact information has to be seen critical. The information on past impacts merely proxies past vulnerability to drought. It does not inform on potential drivers of vulnerability nor provide an actual state of the present situation. Accordingly, the impact forcing driver besides the hazard, namely vulnerability to drought, has to be integrated to drought risk analysis”.

Reply: We agree with this statement, we cannot imply that what happened in the past will reproduce itself in the future, especially because factors such as exposure and vulnerability are not modelled in our study. We will incorporate this statement in the discussion, emphasising that vulnerability to drought is critical to understand drought risk. Also, to model future drought risk, it is necessary to understand how vulnerability will change in the future. In addition to this, as suggested by reviewer #1, we will add vulnerability factors as impact predictors in the RF models and investigate differences in model performance when these factors are included. We will also investigate the predictor importance of these factors in the models. This will integrate drivers of impacts that are not only the hazard, as you mention.

Comment: “**2b The potential of indicators as predictors for drought impacts**
The authors tested the suitability of different indices to be used as predictors for drought impacts and argued that it takes about 15 to 33 months for droughts to cause impacts (though this number depended on the index under consideration). So, if I understand correctly, in order to calculate drought indices that can be useful to reliably predict impacts, one would need sufficiently long records (i.e., 15-33 months of data). Thus, in practice, I wonder how useful it will be to “predict” potential impacts with help of these indices? I would argue that a region will already suffer from severe impacts after more than 1 year of drought conditions and that – after having lost some harvests or after reaching certain thresholds of low groundwater or reservoir levels – there is no added value of starting to look at the data of the past 15-33 months to try to predict the already ongoing impacts... To me that is in fact the nature of droughts, i.e., that they are considered “creeping disasters” with slow onsets and difficult to predict their magnitude and impacts. Therefore, the real question here still remains: **How can we use drought indices over short(er) periods of time to predict impacts of ongoing and potentially much longer droughts, if the study results suggest that only long-term data can actually be used to predict them?** I guess this is somewhat of a chicken or egg dilemma.”

Reply: This is correctly understood, our study shows that in order to calculate drought indices that can be useful to reliably predict impacts, one would need data of the past 15-33 months (for meteorological indices) in this region. The study results show that long-term forecasts can potentially be used to predict long-term impacts. However, to predict impacts at shorter time scales, a sector-specific analysis should be performed (not possible here due to the limited sample size of the impact data). For instance, Sutanto et al. (2020) found that shorter accumulation periods (1-3 months) were best for agricultural impacts and longer accumulation periods for water-borne transportation and water supply. This could mean that if future studies (that have a greater availability of impact data) investigate relationships between indicators and impacts, they might find linkages at shorter timescales for specific sectors. Another potential way to be able to use drought indices over shorter time periods could be to study the predictability of impacts at a seasonal scale. We will discuss this question in the discussion and provide our recommendations on how future studies can address this.

Comment: "3 Technical Comments/Corrections
Page 6, line: 164: where did the evaporation data come from, how was it calculated/measured?"

Reply: To calculate the SPEI, a calculation of a simple climatic water balance (Thornthwaite, 1948) is required. This is calculated using the monthly difference between precipitation and potential evapotranspiration (PET) at different time scales. We used Vicente-Serrano et al. (2014) approach to calculate the PET; this is a simple approach that only requires data for monthly-mean temperature. The function used to compute potential evapotranspiration was from the 'SPEI' R package. We will make this more clear in the data section of the revised manuscript.

Comment: "Page 6, line 184: The climate indicators receive only very little attention in the methods, while they are discussed in much more detail in the results. It is actually easy to overlook their short description in the methods part. They should be explained in more details, especially what their abbreviations mean and why they might potentially be relevant as drought predictors"

Reply: The climate indicators and their abbreviations are introduced in lines 81 to 92, in the introduction. We also briefly explain why they were chosen. To avoid them being overlooked, we will move that paragraph to the 'Methods and data' section.

Comment: "Page 8, censoring methods: CM1 and CM2 seem too similar to me. To me they are not separate censoring methods, because they actually do not "censor" the given problematic cases in different ways, they simply imply a different way of counting the DIOs."

Reply: We realise this and will not use the word 'censor' to describe the different counting methods. We will now describe them as different counting methods and uncertainty strategies.

Comment: "Page 9, Figure 1: colour choices are not optimal, there are too many similar colours that are difficult to distinguish."

Reply: We will change the colours to more distinguishable ones

Comment: "Page 13, line 309: perhaps emphasize that drought indicators are actually negative in case of droughts, which would explain the negative correlations"

Reply: We will add this explanation to this line.

Comment: "Page 13, line 311: NE and CE (the two regions I highlighted above to have the lowest population density) clearly stick out in terms of correlations. The authors should discuss potential reasons for that. Perhaps a closer look at different sectors could help (e.g., less agriculture, less industry in these regions? Or simply less people to notice any impacts?)."

Reply: We will now look at regional differences in sectors to discuss potential reasons for this. We will also discuss that these regions, as you previously mentioned, may be less vulnerable to drought impacts if they are less exposed.

Comment: "Table 2a/Table 2b and Figure 10: as mentioned above, I think CM1 and CM2 are too similar and, thus, demonstrating the results only for those two cases is not showing the full picture. Especially in Figure 10, it would be very easy to add additional bars (with different colors) for CM3 and CM4"

Reply: We will add additional bars or an additional plot to figure 10 to show the full picture, as you mention. The reason why they were not included was because the predictor importance results for CM4, for instance, as discussed in lines 441 to 446 were different than for the other counting methods. This is because it includes impact occurrences in each subregion that affected the whole country or possibly only one specific region but labelled incorrectly, therefore, it most likely represents the indicator-impact links for the whole region of Spain. This means that figure 10 becomes more complex as more counting methods with different results are added.

Comment: "Page 25, lines 479-481: The statement of drought impacts responding fast to hydrological or soil moisture drought is directly implied by the drought propagation chain suggested by Van Loon and Laaha (2015)."

Reply: We will now mention the drought propagation chain suggested and cite these authors in the statement.

Comment: "Page 25, line 491: you cannot be sure that agriculture and livestock farming were the sectors suffering from most impacts, but you can rephrase to that these two sectors were "most frequently reported to be affected". So, my point is that there is a difference between actually experiencing impacts and looking at a list of reported impacts, which could be highly biased."

Reply: We agree and will rephrase this.

Comment: "Page 26, line 514: authors state that due to the reduced sample size of impact reports, the analysis did not include an investigation of sector-specific impacts. However, the authors include Figure 1, which explicitly lists the impacts by sector and different regions, which becomes somewhat obsolete if there is no subsequent analysis of the different sectors."

Reply: Although we were not able to conduct a sector-specific analysis, Figure 1 aids to visualise which sectors were reported to suffer most or least impacts. In lines 491 to 500, we state that the sectors with most frequent impacts are sectors that depend on reservoir systems for storing water, and that this could explain why it takes a long time for precipitation anomalies to propagate to impacts. However, we will now replace Figure 1 in the original manuscript with Figure 1 (displayed on RC1). This is a time series of sector-specific drought impact occurrences for each region. It will help visualise which and how many sectors were reported to suffer most impacts in each region and justify why a sector-specific analysis was not conducted.

We thank you very much for your comments again. We believe that your suggestions will improve the quality of the manuscript.

References:

Sutanto, S. J., van der Weert, M., Wanders, N., Blauhut, V., and Van Lanen, H. A. J.: Moving from drought hazard to impact forecasts, Nat. Commun., 10, 4945, https://doi.org/10.1038/s41467-019-12840-z, 2019.

Thornthwaite, C. W.: An Approach toward a Rational Classification of Climate, Geographical Review, 38, 55, https://doi.org/10.2307/210739, 1948.

Vicente-Serrano, S. M., Lopez-Moreno, J.-I., Beguería, S., Lorenzo-Lacruz, J., Sanchez-Lorenzo, A., García-Ruiz, J. M., Azorin-Molina, C., Morán-Tejeda, E., Revuelto, J., Trigo, R., Coelho, F., and Espejo, F.: Evidence of increasing drought severity caused by temperature rise in southern Europe, Environ. Res. Lett., 9, 044 001, https://doi.org/10.1088/1748-9326/9/4/044001, 2014b.