General response

We thank the two anonymous reviewers for reading our article carefully and providing constructive criticism. We have done further work to account for their suggestions and to address their concerns. In summary, we reduced the length of the paper removing some, not strictly necessary, parts; we highlighted the advance of our paper compared to recent literature on the same case study; and we incorporated the reviewers' suggestions to improve clarity in certain points. We believe that the Reviewer's comments substantially improved the manuscript. The detailed responses are provided in the two attached pdf files. The reviewers' comments appear in black font and our responses in red. All line numbers in the response documents refer to the lines in the revised manuscript without Track Changes (the manuscript is also provided with Track Changes).

Point-to-point response to Reviewer #1

The purpose of this article is to present the multi-aspect study led by the ClimXtreme research network of a dry and hot compound event: the European summer of 2018, with a special focus on Germany. The authors succeed in showing the importance of such a multi-faceted analysis in understanding the drivers and dynamics of such dry and hot compound events. The science presented here is sound, and the article is well written.

We thank Reviewer #1 for their positive and constructive feedback.

However, I believe that the authors should have presented another case study (even if more local). Indeed, this is a long and dense article, as the authors look at different aspects of this compound event, for a case study that has already been intensively documented on different aspects by various publications: exceptionality (e.g. NOAA Global climate report and Met Office report for summer 2018), predictability and drivers (e.g. Dunstone et al. 2019; McCarthy et al., 2019), drought (e.g. Toreti et al. 2019; Peters et al. 2020), dynamics (e.g. Kornhuber et al. 2019; Drouard et al. 2019; Sousa et al. 2019; Li et al., 2020; Spensberger et al. 2020), attribution (e.g. World Weather Attribution Project, 2018; Vogel et al., 2019, Hari et al., 2020). In addition, it has already been regarded as a compound event by previous studies (e.g. Bastos et al., 2021). As the authors point out along the text, most of the findings shown by the authors were already evidenced in previous scientific papers. I understand the argument of the authors on the exceptionality of such a large-scale, persistent, and intense compound event, but I find the paper very long and dense and to me it does not show any substantial new insight on this widely documented compound event. The authors should reduce the length of the paper or better justify the necessity of such a study for the 2018 compound dry and hot event and its added value.

Although we agree that the case of the 2018 European summer climate extremes has already been extensively studied, we would like to further highlight why we chose it for our collaborative paper, and which are the new aspects covered in our study compared to previous ones. Summer 2018 was an extraordinary season for Europe, with many heat and drought records broken in multiple countries and disproportional impacts affecting several sectors over extended areas. In particular, Germany was heavily affected. Here, we used multiple lines of evidence to showcase and explain the exceptionality of the 2018 extremes, ranging from the dynamical evolution of the atmospheric circulation, the co-existence of favourable precursors in the North Atlantic SSTs and the soil moisture state over Europe in general and Germany in particular, the temperature and precipitation records from long-standing weather stations around the country, and the use of two different modelling approaches, a probabilistic one based on a grand ensemble, and a multi-model one focusing on Germany to elucidate the role of anthropogenic warming in the occurrence probability of the heatwave. The April-October period of 2022 in Germany was also an extremely hot and dry one, but it was still less extreme than 2018, as seen in the updated thermopluviogram below (Figure R1, the thermopluviograms were also updated to include 2022 in Figure 2 and A1 in the revised manuscript). In more detail, some of the novel parts of this work are:

- Regarding the dynamical mechanisms, we examined the origin of the air masses for different locations within the three broader regions that were affected by the 2018 summer heatwave (see Figure 5), Iberian peninsula (represented by a grid point over Portugal), central Europe (grid point over Germany), and Scandinavia (grid point over Finland). Further, we provided evidence that for the heatwave peak over the Iberian peninsula in August 2018, Rossby wave activity propagating from the Pacific and via the Atlantic was not one of the driving mechanisms (see Figure 4), but rather local-to-regional advection of air masses originating from Northern Africa (see Figure 5c) were determinant. Therefore, this work is spatially more exhaustive, compared to Spensberger et al. 2020 and Kornhuber et al. 2019, for instance.

- Further, we presented a tailored attribution study, particularly designed for the heat extremes during the 2018 summer heatwave in Germany, incorporating the length of the heatwave in the region, and selecting the CMIP6 models that could better capture these extremes.

Therefore, we believe that this work adds useful pieces to the puzzle of the 2018 European hot and dry extremes and contributes to their better understanding. In conclusion, we have further highlighted these points in different parts of the revised version of the manuscript, and we have reduced the length of the paper to make it more precise.

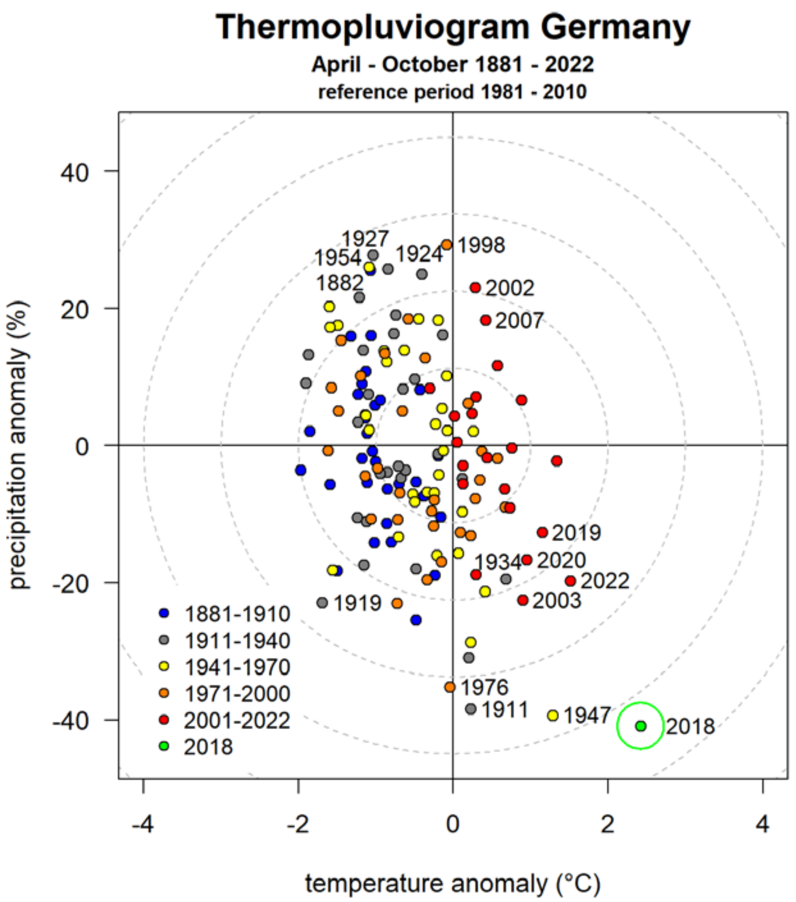

Figure R1. Thermopluviogram for Germany for the growing season April-October, 1881-2022. Year 2018 is highlighted with a green circle. (This updated plot is included in the revised manuscript as Fig. 2)

Additional specific comments:

- The data sub-section is very dense and long. Maybe it would benefit of an italic title for each paragraph to quickly find the piece of information needed.

Thank you for the suggestion, which we followed in the revised manuscript. We also removed the description of the dynamical vegetation model, as we removed this part from the analysis according to the suggestion. The data subsection is shorter and easier to navigate now.

- Lines 190-197: the computation of the 90^{th} percentile differs for the two heatwave indices?

The paragraph has been rephrased in order to clarify the similar definitions of the heat wave indices and metrics (lines 188-193). The computation of both 90^{th} percentiles is based on daily maximum temperature, and daily maximum UTCI, for each day of the year. Our heatwave intensities are cumulative intensity measures (cumulative heat and cumulative UTCI, here in short called cUTCI) that take into account all heatwave days within the stated period.

Sub-section 2.2.2: I am not sure that three drought indicators are necessary as the purpose of the study is not to compare drought indices or to deeply evaluate the 2018 drought. Mentioning and showing only the SPEI is sufficient to evidence the occurrence and intensity of the drought, as the SPEI is a widely used drought index that considers both precipitation and evapo-transpiration. The SPI is not shown in the main body and does not bring any additional information. And the results shown with the climate network approach could be shown in another way with the SPEI. Showing only one drought indicator would contribute to lighten the text.

We thank the reviewer for their feedback on the drought indicators. We agree with the comment and given there is no much further insight offered by either the SPI, or the network indicator, compared to the SPEI, we have removed these two to make the text lighter and shorter.

Lines 230-232: The way the blocking index is computed is not clear. Is it a "hybrid" index that looks for an inversion of the Z500 meridional gradient and a strong Z500 anomaly? Are there any spatial and temporal constraints?

Thank you for the good remark. Indeed, the used blocking index is a kind of a "hybrid" index. First, the daily inversion of the meridional Z500 gradient is determined based on a modified version of the index from Scherrer et al. (2006). In addition, an associated area with strong Z500 anomalies (above 1 standard deviation) of at least $1.5\times10^{6}\,\mathrm{km}^{2}$ is selected. Both conditions must be met. A subsequent tracking algorithm is applied to daily blocked areas to select blocking events with a duration of at least 4 days. The method is described in more detail in Schuster et al. (2019). In addition to the "non-hybrid" index described in Schuster et al. (2019), here we expanded the definition to a hybrid index by selecting strong Z500 anomalies. We have clarified this part in the revised document (see lines 219-223).

References

Scherrer, S. C., Croci-Maspoli, M., Schwierz, C. and Appenzeller, C.: Two-dimensional indices of 1020 atmospheric blocking and their statistical relationship with winter climate patterns in the Euro-1021 Atlantic region, Int. J. Climatol., 26(2), 233–249, doi:10.1002/JOC.1250, 2006.

Schuster, M., Grieger, J., Richling, A., Schartner, T., Illing, S., Kadow, C., Müller, W. A., Pohlmann, 1029 H., Pfahl, S. and Ulbrich, U.: Improvement in the decadal prediction skill of the North Atlantic 1030 extratropical winter circulation through increased model resolution, Earth Syst. Dyn., 10(4), 901–917, 1031 doi:10.5194/ESD-10-901-2019, 2019.

· Line 259: are the soil moisture LPJmL simulations absolutely necessary for the paper? It would also contribute to reduce the length of the paper.

We agree with the reviewer that the LPJmL simulations are not strictly necessary for the paper, indeed. We thought that this is a good addition to the observations, as it confirms the observational evidence of the exceptionality of the 2018 drought. However, given that we wanted to reduce the length of the paper, we followed the reviewer's suggestion and removed this part in the revised version.

· Figures 1d and 1e: you could plot the SPEI value only when it is below the drought threshold.

Thank you for the suggestion. Figures 1d and 1e now only show values of SPEI below -1, which denote drought conditions (see below and revised Figure 1 in the manuscript).

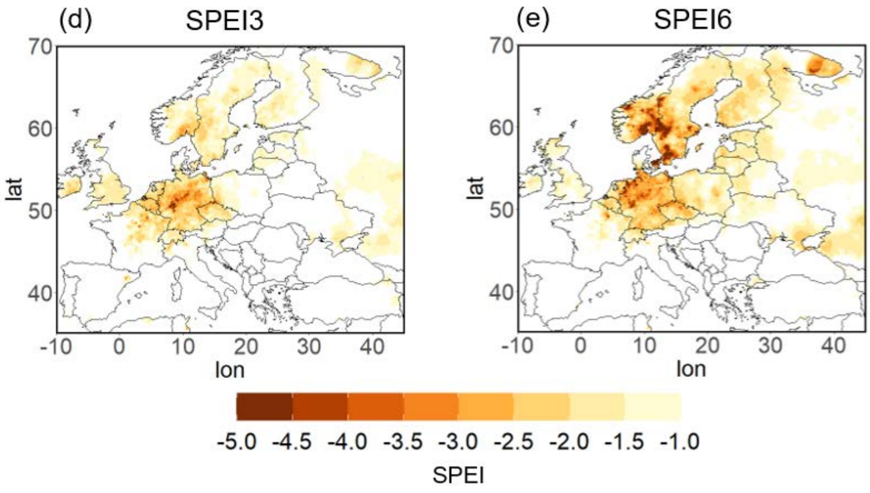

Figure R2. (d) SPEI3 August. (e) SPEI6 August. Only SPEI values below -1 are shown, in order to highlight drought conditions. (The updated plots are included in the revised manuscript as Fig. 1d and 1e).

· Lines 364-365: could you show the thermopluviogram for the Scandinavian region as well?

The extensive station data network for Germany that was used for the thermopluviogram was provided by the German Weather Service (DWD). In the following plot (Fig. R3), you can see a thermopluviogram for Sweden for the summer months (JJA), which also highlights the exceptionality of the 2018 summer in terms of drought and heat there. However, due to limited data availability we could not do a plot for the whole Scandinavian region.

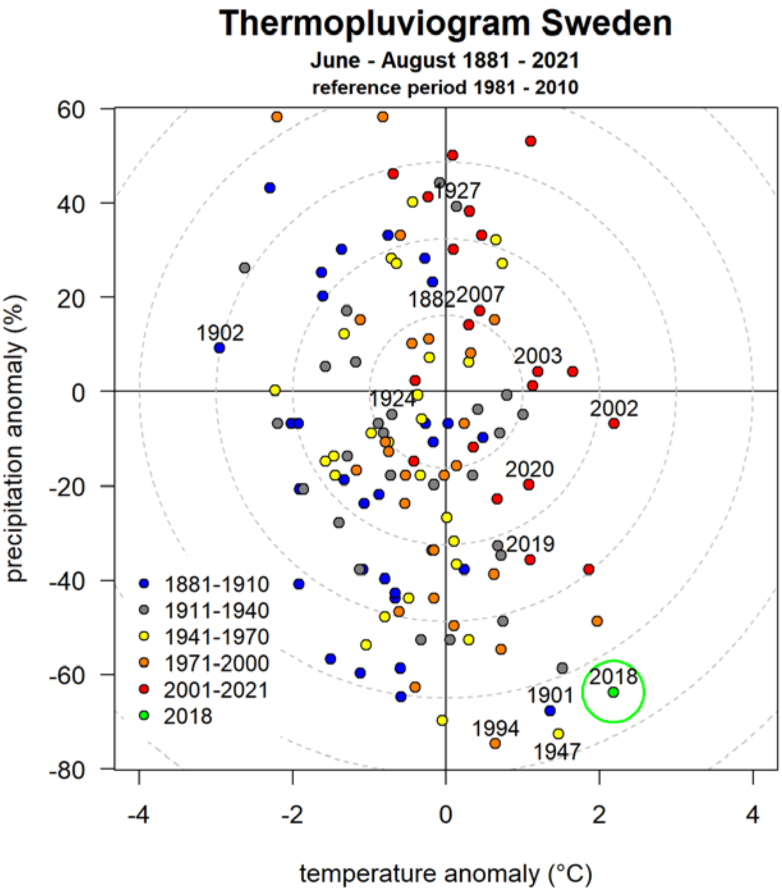

Figure R3. Thermopluviogram for Sweden for summer (June-July-August), 1881-2021. 2018 is highlighted. Input data from the Swedish Meteorological and Hydrological Institute (SMHI; https://www.smhi.se/en/climate/climate-indicators/climate-indicators-precipitation-1.91462).

- Figure 4: Could you show the NAO index for this season as you do for the blocking index?

We added a panel with the NAO index for May-September 2018 to Fig. 3 (Fig. 3c), shown also below. As discussed, the NAO was predominantly positive during this period:

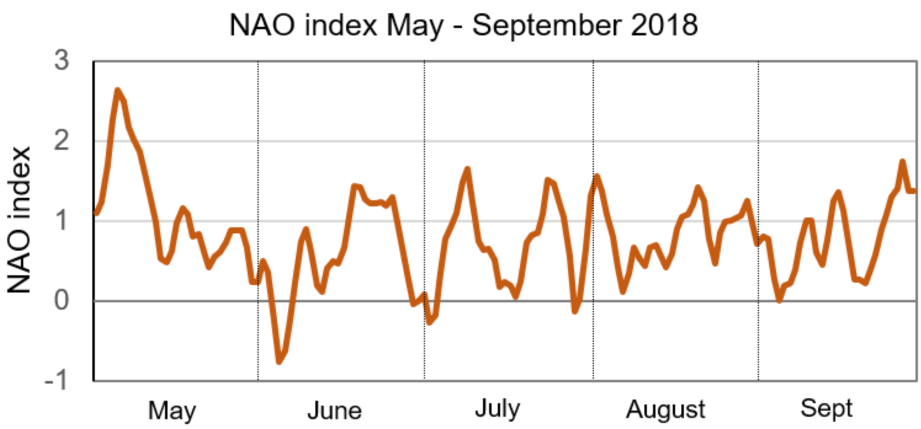

Figure R4. NAO index for May-September 2018. Input data from CPC (https://ftp.cpc.ncep.noaa.gov/cwlinks/norm.daily.nao.index.b500101.current.ascii). (This plot is included in the revised manuscript as Fig. 3d)

- Lines 487-490: You should also cite Dunstone et al. 2019: they studied the predictability of this summer season and evidenced the role of this tripole.

- Lines 490-496: The lack of precipitation is also shown in Toreti et al. 2019.

- Lines 504-506: Add a citation.

- Sub-section 3.4: you should cite Vogel et al. 2019 in this sub-section

- Lines 655-656: Cite Dunstone et al. 2019.

Thanks for all the good advice, we have added the suggested and additional relevant references in the different parts of the revised manuscript (see lines 476; 482-483; 493-496; 543-546; 648) .

Technical corrections:

- Line 468: the closing parenthesis is missing.

- Figure A2, line 702: should be “(b)” instead of “(c)”.

Thanks for spotting those mistakes, we have now corrected them.