Response to referee comments on acp-2021-297

The impact of atmospheric blocking on the compounding effect of ozone pollution and temperature: A copula-based approach

Noelia Otero, Oscar E. Jurado, Tim Butler and Henning W. Rust

General comment

We would like to thank the editor and referees for their comments on the manuscript.We really appreciate the time spent in reviewing the manuscript and we apologise that we did not adequately address the comments before. In this second review stage, we have carefully revised the main criticisms and in response to this, substantial changes have been done in the manuscript. Please note that the changes have been applied in the revised version. A marked-up version of the manuscript is included. Changes are shown in red script and the deleted text is shown as cross out sentences. Here we provide our responses. The comments from the referees are in bold script and our responses are given in standard script.

Response to Referee #2

Main criticisms.

1. Reviewer 1 stated: "I assume that the authors treat all days equally in their distribution (e.g., in line 177/figure 2 for the exceedances of the 95th percentile of temperature). To me this is flawed as the authors consider the months April-September and the probability for temperature extremes is not equally distributed across these months. So, e.g., days in July are way more likely to be in the upper tail (even if they are not exceptional), while this might even be impossible for days in April. This should to be clarified and/or resolved."

The reviewer has raised an important point. The authors address this point in the response, saying, "We agree with the referee that temperature extremes will be in the upper tail more likely in July or August than in April." But the authors have not revised the text sufficiently. It's true a new sentence has been added: "For both variables, we have calculated the anomalies with respect [to] their corresponding climatology during the ozone season (i.e. April-September) for the whole period of study 1999-2015." But does this mean that daily anomalies were calculated – e.g., the anomaly on April 1, 2015, at a particular station relative to all April 1 data at that station? In fact, both reviewers were confused about the construction of the anomalies.

What I think the authors mean is that the anomalous temperature and ozone values were calculated separately for each ozone season, with the 95th percentile of each variable comprising the highest ~10 daily temperatures and ozone concentrations during the 183 days between April 1 and September 30. Is that right?

Importantly, the authors also need to acknowledge in the text the weakness of their approach to construct anomalies, as pointed out by Reviewer 1. They should provide (in the text) their rationale for applying this approach despite its weakness.

We realised that there was a misunderstanding about the construction of the anomalies and it was not sufficiently clarified in the previous version. Below, we provide a better explanation about the anomalies and the use of the 95th percentile for defining the extremes. We hope that the following explanations clarify the referees concerns. We have accordingly modified the text in the revised version of the manuscript, specifically, in Section 3.1 in the following lines (in the marked-up version):

L196-201

We start by examining the impacts of blocks on the anomalies of ozone and temperature (separately), in order to establish a comparison of anomalies across different stations. $MDA8O_3$ anomalies were calculated as the difference between $MDA8O_3$ values and the average of $MDA8O_3$ over all days in April-September in the period of study 1999-2015. This average is obtained individually for every station. Similarly, Tmax anomalies were calculated with respect to the average value over all Tmax values from April-September during the same period. It is important to highlight that all calculations were applied separately for each station, and therefore the number of blocking days might differ across the different stations.

L213-221

To this end, we do not work with anomalies but we fix a threshold for $MDA8O_3$ as well as for Tmax. The absolute values for these thresholds vary among stations. A transparent way to set these thresholds are quantiles, i.e. values with a specified non-exceedance probability. For each station, we use the 0.95-quantile (or 95th percentile) from the sample restricted to April to September and thus get individual thresholds for all stations reflecting their local climatology. In the following, we define days with $MDA8O_3$ exceeding this threshold as extremes. Then, we obtain relative frequencies by dividing the number of extreme days with a simultaneous blocking by the number of total days in the data set restricted to April to September (i.e. $\hat{p} = extremeswithblocking/3111$) .A similar approach was applied in Ordóñez et al. (2017) that calculated the percentage of blocking days with $MDA8O_3$ values above the 90th percentile. It must be noticed that the spatial variability of high levels of ozone is very heterogeneous (Fig. S2).

L224-237

The same procedure using the 95th percentile was applied for identifying days of Tmax exceedances and days above the 95th percentile of the Tmax (Fig. S2) were classified as exceedances. We acknowledge that in the case of Tmax, the number of exceedances above the 95th percentile might be not equally distributed across the ozone season (i.e. this threshold is more likely to be exceeded in July and August than it is in April and September). While this could be corrected by either using a threshold that varies seasonally or by removing the seasonal trend in the data, we would like to stress that the main goal of this study is to quantify the impacts of blocking on the upper-tail dependence between $MDA8O_3$ and Tmax over the entire ozone season. Our main interest is in the physiological effects of such compound events, for which only absolutely high temperatures (as they tend to occur in July or August) are relevant.
As in other studies (Schnell and Prather, 2017), we use the 95th percentile over the period April to September. A lower threshold, e.g. the 90th percentile would lead to many temperature values not being physiological relevant; a higher threshold, e.g. the 99th percentile would lead to a strong reduction in the number of data available for the subsequent copula modelling. The 95th percentile-based definition to examine the individual impacts of blocks on $MDA8O_3$ and Tmax it is also justified to be consistent with the joint probability analysis, for which the 95th percentile is applied for the risk assessment (see below). Moreover, earlier studies used a similar threshold-percentile based definition to assess the links between temperature extremes and atmospheric blocking Pfahl and Wernli. (2012).

2. Reviewer 2 asked for greater clarification on how this paper builds on previous work. The revised text does indeed begin to address this request. Can the authors also say that the copula based approach allows a quantification of the probability of joint exceedances?

Thank you for this comment. As stated in the introduction, previous works examined the individual impacts of atmospheric blocking on surface ozone (Ordóñez et al., 2017) or temperature (Pfahl and Wernli., 2012), but our study provides for the first time (to our knowledge) a quantification of the impacts of blocks in the compounding effect of ozone and temperature. Indeed, copulas enable to assess their joint dependence. Therefore, we are confident that the copula-modeling approach is robust and solid to quantify the effects of atmospheric blocking. Extra text has been added in the revised version (i.e. in the introduction section, L81-84 in the marked-up version).

3. Reviewer 2 also asked for some discussion of the drivers of the spatial patterns of the relationships between blocking conditions, ozone, and temperature. The authors responded that this was beyond the scope of the text, saying "Since the present study employs purely statistical techniques, mechanistic explanations for the effects cannot be produced, but this remains an interesting topic for future work." I disagree. There exist many papers relying on statistics that also offer mechanistic explanations for results. The literature is there – e.g., Ordonez et al. (2017) and Sousa et al. (2018). What accounts for the spatial variation in the drivers of high ozone and temperature? Are there other drivers besides blocks for extreme ozone or temperature events? There is some discussion of subtropical ridges but it is hard to follow. The reader is curious and seeks more than just a reporting of results. An example of text that provides insufficient interpretation is the following (Lines 318+): "However, we found a significant increase in the conditional probability over the north-west stations and a slight increase over the central-east stations [Figure 5f]. This suggests that over such regions ozone extremes tend to occur given high temperatures which are strongly connected with atmospheric blocking. This is likely due to the position of the block during the ozone season covering spring and summertime when the increased solar radiation lead to warm temperature in the blocked regions." Where exactly is the block position? Wouldn't the relationship of high temperatures leading to high ozone hold true throughout the domain? Figure S1 shows the frequency of blocks during the ozone season, but that is not the same as "the position of the block." In any event, the pattern in Figure S1 is not similar to that in Figure 5f. Finally, does the duration of the blocks have an impact on the copula results?

I recommend that Section 3.1 (Impact of atmospheric blocking on ozone and temperature) and Section 3.2 (Copula results) each begin with a detailed description of the results and then conclude with a short paragraph interpreting the results for that section. The interpretation would include an account of spatial variability of all results. There exists sufficient literature for the authors to begin to interpret this spatial variability, though there will also likely be gaps in our knowledge. Citations to other papers should briefly describe the mechanisms that these papers suggest.

Thank you for this comment. Following the referee suggestion, Sections 3.1 and 3.2 have been modified. In particular, substantial changes have been applied in Section 3.1 to better clarify the construction of the anomalies as well as the extremes identification. Moreover, we conclude each subsection with a short paragraph to summarizes the main results while linking our findings to previous works.

4. Reviewer 2 asked about the impact of trends on the results. In response, the authors again state that "For both variables, we have calculated the anomalies with respect [to] their corresponding climatology during the ozone season (i.e. April-September) for the whole period of study 1999- 2015." As stated in #1 above, I think that means that the anomalies are calculated with respect to all values recorded during each ozone season separately (and not in fact over the "whole period of study").

In any event, if trends in either ozone or temperature have occurred, then the extremes may become more (or less) extreme over the 17 years of study, and that could muddy the relationship of blocking conditions and these variables. For example, Yan et al. (2019) find a

rapid decline of relatively high ozone concentrations from 1995-2012, especially in rural areas. At the very least, the authors need to acknowledge these trends in the text and consider the impact of these trends on their analysis. Yan, Y., J. Lin, A. Pozzerc, S. Konga, and J. Lelieveld (2019), Trend reversal from high-to-low and from rural-to-urban ozone concentrations over Europe, Atmos. Env., 213, 25-36.

As mentioned in the previous comment, in the revised version we have better clarified the construction of the anomalies. Following the referee suggestion regarding the trends, we acknowledge this limitation in the last section of the manuscript. Specifically in L436-447 (in the marked-up version):

While maximum temperature have shown upwards trends for the past decades (Jacob, 2013), the trends of surface ozone concentrations over Europe are no clear. Previous trends analysis showed a clearer decreasing trend of ozone peaks during the period 2000–2008 over most of the European sites, but not significant trends were found for the recent period 2009–2018 (EEA, 2019). Since our main objective focuses on the dependence between ozone and temperature, we might expect that changes in their relationship could be also reflected in the impacts of atmospheric blocking. However, due to the complexity in the temperature dependence of ozone Otero et al. (2021) and the changing emissions of ozone precursors, further analysis should be required to investigate the influence of persistent atmospheric conditions while accounting for changes in the temperature-ozone relationship. In spite of this limitation, our results are in a good agreement with previous works that examined the individual effects of blocking on either temperature Pfahl and Wernli. (2012) or ozone (Ordóñez et al., 2017).Moreover, here we provide a first quantification on the impacts of blocks on compound events of ozone and temperature extremes.

5. Reviewer 2 commented that lapses in English occur with a frequency of 4-5 per page. These lapses are still there – e.g., "especifically," "the probabilities associated to. . . ," improper use of "with respect" and "allow to," "Artic," "bock," and many others. The authors should employ an editor to fix these minor but distracting errors.

We apologise for this. The manuscript has been carefully reviewed.

6. Reviewer 2 commented that Figure labels are too tiny to read. They continue to be too tiny, both in the main text and the Supplement. For example, the tiny B=0 and B=1 text at the top of many panels is so small that it's easy to miss. Numbers and units beside the color bars are also tiny. Minor comments.

Figures 2,3,4 and 6 in the main text and Figures S1,S2 in the supplementary material have been updated.

Line 104. "The BI was computed through the Free Evaluation System Framework (see Richling et al. (2015) for more details), specifically with the single plug-in corresponding to the blocking-2d (Freva, 2017)." The average reader will not understand this sentence.

This sentence has been changed.

Table 1. There appear to be some typos in this table – e.g., in the Clayton equation. Equations 2-4. The variables u and v should be defined here, not just in the Table.

Thank you. It has been corrected.

Line 271-2. The text states: "For the COND probability, both the computation domain and the critical region evolve when moving along higher temperatures. . . " This is not clear. What is meant by "critical region" and "computation domain"?

Thank you for the comment. We have clarified this sentence with the following extra text: "both the computation domain (i.e. the joint space where the probability of exceedances is calculated) and the critical region (i.e. the regions of exceedances of ozone conditioned by temperature)". Figure S5 shows the space where the joint probabilies are estimated for the *COND* case. In addition to the text, we have considered to move Fig.S5 from the supplementary material to the main text (now, Fig. 5) for a graphical explanation of the three hazard scenarios in the manuscript.

References

EEA, E.E.A., 2019. Air quality in europe-2019 report. Tech. rep.

Jacob, D., 2013. EURO-CORDEX: New high-resolution climate change projections for european impact research. Reg. Environ. Change 1–16.

Ordóñez, C., Barriopedro, D., García-Herrera, R., Sousa, P.S., Schnell., J.L., 2017. Regional responses of surface ozone in europe to the location of high-latitude blocks and subtropical ridges. Atmos. Chem. Phys. 17, 3111–3131. https://doi.org/10.5194/acp-17-3111-2017

Otero, N., Rust, H.W., Butler., T., 2021. Temperature dependence of tropospheric ozone under NOx reductions over germany,. Atmospheric Environment 253, 1352–2310. https://doi.org/https://doi.org/10.1016/j.atmosenv.2021.118334.

Pfahl, S., Wernli., H., 2012. Quantifying the relevance of atmospheric blocking for co-located temperature extremes in the northern hemisphere on (sub-)daily time scales. Geophysical Research Letters 39, L12807. https://doi.org/10.1029/2012GL052261

Pusede, S.E., Gentner, D.R., Wooldridge, P.J., Browne, E.C., Rollins, A.W., Min, K.-E., Russell, A.R., Thomas, J., Zhang, L., Brune, W.H., Henry, S.B., DiGangi, J.P., Keutsch, F.N., Harrold, S.A., Thornton, J.A., Beaver, M.R., Clair, J.M.St., Wennberg, P.O., Sanders, J., Ren, X., VandenBoer, T.C., Markovic, M.Z., Guha, A., Weber, R., Coldstein, A.H., Cohen, R.C., 2014. On the temperature dependence of organic reactivity, nitrogen oxides, ozone production, and the impact of emission controls in san joaquin valley, california. Atmos. Chem. Phys. 14, 3373–3395. https://doi.org/10.5194/acp-14-3373-2014

Schnell, J.L., Prather, M.J., 2017. Co-occurrence of extremes in surface ozone, particulate matter, and temperature over eastern north america. P. Natl. Acad. Sci. USA 114, 2854–2859. https://doi.org/10.1073/pnas.1614453114

Sousa, P.M., Barriopedro, J.D., Soares, P.M., Santos, J.A., 2018. European temperature responses to blocking and ridge regional patterns. Clim. Dynam. 50(1-2), 457–77. https://doi.org/10.1007/s00382-017-3620-2