Author response to reviews of "North Atlantic seasonal climate variability significantly modulates extreme winter Euro-Atlantic extratropical cyclone hazards" by Maycock et al., submitted to NHESS

We thank the Editor for sourcing three detailed reviews of our study. We thank the reviewers for their time in providing constructive comments to improve the manuscript. We have taken on board many of the suggestions. We respond to the specific points raised in blue.

Review by Mika Rantanen

This paper investigates the relationship between large-scale climate modes and ETC-related hazards in Europe. The authors track cyclones, calculate their hazard footprints and then use linear regression to find how much the ETC-related extremes change with respect to PC1 (North Atlantic Oscillation) and PC2 (East Atlantic pattern). The key result is that PC1 or PC2 alone exhibit increases in hazards in relatively different geographical areas (i.e. PC1 in the east and north of the UK, but PC2 mainly in the west and south). In addition, there are areas which exhibit signals for several hazards at the same time, and areas where both PC1 and PC2 affect simultaneously.

I like the research idea and I think this is definitely something which is worth publishing in NHESS. The used datasets are appropriate for conducting this kind of study. I also liked that negative results (SDI) were mentioned.

However, I had some concerns related to how the key results are presented. I think this could have been done in a more explicit/quantitative way (see comment 1). In addition, I'm afraid that the daily precipitation associated with the ETCs might be overestimated (see comment 2). I hope that the authors could address these concerns before the publication of this study.

We thank Dr Rantanen for taking the time to provide a thorough review of the manuscript and for their supportive comments and constructive suggestions to improve the manuscript. We are grateful for their constructive suggestions to improve the manuscript. We respond to their points below.

Major comments:

1. The presentation of the results. I don't know how to really formulate this, but I got the feeling that presenting the main results only in a rather qualitative way with Figs. 3-7 leaves the results a bit incomplete. Now you go through the regions rather subjectively (i.e. increase here, decrease there and so on). Could this be done in a more quantitative way, for example selecting beforehand relevant regions (domains) from Europe, e.g. countries or more wider regions such as Scandinavia, Western Europe, etc. And then calculate the regional statistics of how NAO and EAP affect the ETC hazards. These could be presented for example with boxplots which compare the climatology and then a unit increase of PC1/PC2. For example, the climatological daily ETC-precipitation in Scandinavia is this, but when NAO is positive, it's this, and so

on. This would provide more quantitative information on the regional distribution of the results. I hope you get the idea!

Thank you for this useful suggestion. We intended for Fig. 7 to display this information spatially, but we recognise it is difficult to extract detailed quantitative information from the maps. We have applied the 0.5 Mm^2 land regions defined by Stone et al. (2019) and have added a figure showing boxplots for the land-based hazards for these regions. For the ocean-based hazard we use the Marine Strategy Framework Directive (MSFD) European regional seas regions.

Stone, D.A. A hierarchical collection of political/economic regions for analysis of climate extremes. Climatic Change 155, 639–656 (2019). https://doi.org/10.1007/s10584-019-02479-6

MSFD regions: https://www.eea.europa.eu/en/datahub/datahubitem-view/7144675c-5c84-456f-92e0-8f832239d880

2. Precipitation footprints. I was not entirely convinced by the way the daily precipitation is assigned to the ETCs. Most importantly, you consider daily (24h) precipitation, but the passage of an ETC can last much less than 24 hours and can occur during two consecutive calendar days. For instance, if an area of ETC (i.e. the 10° circle) passes over a particular grid cell in 12 hours, say from 18 UTC to 6 UTC. What is the period used for calculating the daily precipitation that is attributed to the ETC? Is it a moving 24 hour window, i.e. the previous 24 hours after the passage, or some fixed time interval, like 00-00UTC? This can cause problems especially at the outer edges of the 10° circles, which are only briefly affected by the passage of the distant ETC, but the precipitation is still counted from a 24-hour duration, resulting in exaggerated ETC-related precipitation values. Or am I missing something here?

   The precipitation is the 24h total for a calendar day and does not account for the timing of a cyclone passage which may span >1 day. The index is equivalent to the Rx1day wettest day metric applied to the cyclone related precipitation in the winter season. Rx1day is commonly used to assess precipitation extremes (e.g., Seneviratne et al., 2021). We agree that this metric does not necessarily capture the cumulative precipitation at a location from a cyclone. We have repeated the analysis using the maximum cumulative precipitation from each cyclone at a location and include these results in the Supporting Information.

Other comments:

Section 2. It seems that the whole analysis is restricted to the NH winter but it would be good to mention the months (Dec-Feb) explicitly in the Methods section. Currently, this is mentioned only in Section 2.3 but I guess it applies to the whole analysis. Which leads me to the 2nd question. Why only DJF? At least in Fennoscandia, November is often a very active month in terms of windstorm hazards.

We have added a sentence at the end of Sect 2.2: “The analysis focuses on the boreal winter season from December-February (DJF) when the North Atlantic storm track is most active, so the ETC tracks are filtered to retain DJF storms.”

Section 2.3. North Atlantic modes of variability. I think section 2.3 is a bit incomplete. It lacks justification why you chose the domain which you chose (90W-40E, 20-80N). Furthermore, I think this area is often called the *Euro-Atlantic* sector as it extends up to 40E, but you talk about the North Atlantic sector which is slightly misleading, given the area. Also, some studies (e.g. https://rmets.onlinelibrary.wiley.com/doi/10.1002/qj.3341) call the 2nd EOF as Scandinavian or European blocking. Is the East Atlantic pattern the same as Scandinavian blocking? If not, it might be reasonable to mention this in the text. It might help if the regression/correlation patterns against MSLP are shown, for example in supplementary material.

The domain follows Hurrell (1995), we have renamed this as the Euro-Atlantic sector. EOF2 is equivalent to the Atlantic Ridge pattern, this has been added. We have added a plot showing the EOF patterns to the supplementary information.

L46 and thereafter. You often cite Degenhardt et al. 2022 but there is only Degenhardt et al. 2023 and 2024 in the reference list.

Thanks for spotting this. It was due to the online appearance year being different from the print issue year. Corrected.

L136. This should be Section 2.4

Thank you for spotting this! Corrected.

L155: these metrics? which metrics?

Amended to “We also tested our analysis on these variables…..”

L157: Here you mention that linear regression performs poorly if the data is non-linear and contains lots of zeros. But isn’t that the case for ETC-hazards too, for those regions which infrequently see ETCs during DJF months? So how do you deal with those regions that are far from storm tracks, and might not see ETCs every winter? Are there those regions at all?

This is a great question. The footprints are sufficiently large and the number of storms tracked per season sufficiently high, that in all seasons there is at least one value per gridcell for the domain studied here. If we extended further east that would become increasingly problematic.

L182: are shown

Corrected to “are shown as”

L200: show a reduction? How can you see this as the colour bars in Fig. 3 only show positive values? I see that the absolute anomalies in Fig. S3 also have negative values, but I don't understand why the percentage anomalies in the ΔPC1 and ΔPC2 maps in Fig. 3 only show positive changes?

Thanks for spotting this mistake. We have extended the colour scales in Fig. 3 to include negative % changes. This shows the expected signals consistent with Fig S3.

L287. Previous work. Here it would be good to cite the actual previous work.

Citations added.

Fig. 5 and 6: the titles show 1981-2010, should it be 2020? And why does Fig. 7 have 2021 in its title?

Thanks for spotting these mistakes. All corrected to 2020.

Section 4. Please consider writing something about the limitations of your analysis. For example, the linear model does not naturally explain all the variability in ETC-related hazards. What other factors are there which add the variability? How could you improve your work in the future?

We have added to Sect 4: "The analysis assumes the relationships of the maximum winter ETC hazards with the seasonal models of variability are well described by a linear model. While we have shown that some common ETC and hazard indices are not well suited to the application of linear regression at the grid point level, notably the storm damage index (SDI) and discrete variables like storm frequency, there also remains unexplained interannual variance for the other ETC hazards studied here. It would be valuable to explore these residuals in further work and to test other higher order statistical models or machine learning techniques which are suited to identifying non-linear relationships."