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.

Reviewer 2

Summary: I think there is potential for this work to be developed into a very useful contribution to our understanding of the connections between weather hazards and variability on larger (both spatial and temporal) scales. To move towards that potential, a couple of important elements in the current manuscript need to be addressed, as follows:

We thank the reviewer for taking the time to provide a thorough review of our study. We are pleased they see the value of our work and thank them for their constructive suggestions which we have considered and respond to below.

Main Comment

Reading through the analysis, the question I kept asking myself is: what is gained in the study by including ETCs? For Figs. 3 – 6, it is not clear to me how the ETC footprint step is useful. For instance, you could look at the relationship between the extremes for each of those hazards (regardless of ETC association) and the NAO and EAP. You might even have more data, which would make the analysis less noisy. So the question is: what does the utilization of ETCs add to the story? Does the link to the ETCs give us longer timescales in predictability? Or do they provide something else? This needs to be explained.

Thanks for the comment. ETCs are the primary feature of interest for winter weather forecasts in Europe. The starting point is therefore the extensive interest and literature on European weather hazards from ETCs; the goal is the understand how these hazards are shaped by seasonal North Atlantic climate variability which may be predictable. The goal is not to understand the weather hazards associated with the modes of variability themselves, since these modes are not a feature of weather forecasts. In that sense, the goal is to better connect weather and climate in the context of seasonal variability. Regardless, in winter the extreme wind, precipitation and coastal wave hazards analysed would almost exclusively be related to ETCs. There is an added benefit that if the modes of variability can be skilfully predicted by seasonal forecast models (e.g., Scaife et al. 2014), we would have early information about the likelihood of an impactful ETC affecting in different parts of Europe.

Reference

Scaife, A. A., et al. (2014), Skillful long-range prediction of European and North American winters, Geophys. Res. Lett., 41, 2514–2519, doi:10.1002/2014GL059637.

Related to this: In Section 3.2 (Line 211), based on the title, my hope was that you would focus on the compound events caused by individual ETCs, but you actually go in the opposite direction (based on my interpretation of what you write on Line 216). You might want to consider including an analysis that is focused on describing the ETCs that cause the compound hazards.

The rationale for this choice is that the timeframe for society to recover from a severe hazard would be longer than one season, meaning that damage to e.g., infrastructure occurring from compound hazards within the same season could be more impactful than a single hazard even if they do not occur very close together in time.

Minor Comments

Unfortunately, I think the title is too general of a statement. For instance, when I read that title, I think: I have high confidence in that statement, without doing any research. So, I suggest you come up with a new title that demonstrates more of the knowledge gained by this research.

Here is a possible replacement (mostly taken from text that you wrote in the introduction): “The Observed relationships between ETC hazards and the NAO and EAP on Seasonal Timescales.”

We have suggested a new title of “The observed winter relationships between extreme North Atlantic extratropical cyclone hazards and modes of seasonal climate variability” which avoids using acronyms and makes clear the study focuses on winter.

Line 19: Throughout the abstract and the text, I think it will be more intuitive for the reader if you replace “PC1” with NAO and “PC2” with EAP. I appreciate that PC1 and PC2 are more precise, but they offer less connotation with physics.

Thanks for the suggestion. We also considered this and decided to stick with the PC notation because we refer to these quantitatively at some points in the text and we feel it is clearer that they are standardized indices when referred to as PCs.

Line 46: In this section, you may also want to refer to Pinto et al. 2009 (DOI 10.1007/s00382-008-0396-4)

Added, thanks

Line 51-52: You write: “A positive EAP phase is associated with an increase in cumulative winter storm severity in the UK, which is weaker than for the NAO …”

What is weaker, the storm severity or the association? Please re-write the sentence to clarify.

Amended to: “A positive EAP phase is associated with an increase in cumulative winter storm severity in the UK, though for an equivalent change in index the amplitude of the storm severity signal is weaker than for the NAO,….”

Line 82 - 86: You have provided some discussion on the potential bias in the reanalysis. Please expand a bit more on this. Please add some discussion specifically about the wave swell. And for winds and precipitation, some examples that you could reference:

Ramon J, Lledó L, Torralba V, Soret A, Doblas-Reyes FJ. What global reanalysis best represents near-surface winds?. Q J R Meteorol Soc. 2019; 145: 3236–3251. https://doi.org/10.1002/qj.3616

Chen, T.-C., Collet, F., & Di Luca, A. (2024). Evaluation of ERA5 precipitation and 10-m wind speed associated with extratropical cyclones using station data over North America. International Journal of Climatology, 44(3), 729–747. https://doi.org/10.1002/joc.8339

Thanks for suggesting additional references for ERA5 evaluation. We have expanded this paragraph in Sect 2.1 as follows: "Winter average near-surface wind speeds in Europe in ERA5 have been shown to agree better with observation towers than several other reanalysis datasets (Ramon et al., 2019). As is standard for climate models, wind gusts are post-processed in ERA5 following the approach described in ECMWF (2016). Comparison with meteorological station data in Sweden indicates strong wind gusts (>~15 m/s) are generally underestimated in ERA5 (Minola et al., 2020). This is consistent with Chen et al. (2024), who evaluated ERA5 against weather station observations in North America and showed that in DJF spatially-averaged near-surface wind speeds within ETCs are well represented (r ~0.9), but wind speeds associated with the most intense ETCs and local extremes within ETCs are generally underestimated. Lodise et al. (2024; their Fig 7) also compared Northern hemisphere ETC wind speeds in ERA5 with radar altimeter measurements and found ERA5 has a low bias by ~5% in the region of strongest 10m wind speeds on the eastern hemisphere of the cyclone relative to the translational direction. For significant wave height, Bessonova et al. (2025) and Fanti et al. (2023) compared ERA5 to global buoy measurements and found an underestimation in ERA5 which was most pronounced for larger wave height measurements. Lodise et al. (2024) also found that in ERA5 significant wave heights within Northern hemisphere ETC footprints are biased low by ~5% compared with radar altimeter data. For daily precipitation, ERA5 shows the smallest biases in the winter extratropics compared to other global regions and seasons (Lavers et al., 2022) and captures observed variability across Europe with significant skill compared with E-OBS observations (Bandhauer et al., 2021). However, ERA5 underestimates the magnitude of extreme daily precipitation but it can generally capture the location and timing of precipitation extremes (Lavers et al., 2022). Therefore, based on studies that have evaluated ERA5, we conclude that the extreme European ETC hazards derived in this study are likely to be conservative estimates."

Line 107: What is "Rx1 day metric"? I tried searching within your doc and did not find Rx anywhere else. Sorry if I missed it.

We have clarified this as follows: "The first measure relates to the likelihood of flooding, particularly pluvial flooding in urban areas, and is akin to the Rx1day metric which represents the wettest calendar day in the year and is widely used in the climate extremes literature (e.g., Seneviratne et al., 2021)."

Line 194: You write: "The lack of significant relationship with PC1 could be a result of the relatively noisy data, since at each gridpoint we are taking the wettest day in the winter associated with any ETC and regressing this against the seasonal NAO." Have you tried interpolating the seasonal NAO to daily? Or is there a reason you have to use the seasonal NAO? If so, remind the reader of that reasoning. Also, have you tried relaxing the definition of the "extreme" precipitation to include more data (i.e., instead of using the maximum, use the top N percentile)?

We use the winter average NAO because it can be predicted on seasonal timescales (Scaife et al. 2014). Calculating the NAO on daily timescales would negate the utility of the low frequency long-range predictable signals which motivate the study. We have calculated the relationships using the cumulative precipitation at each location over the ETC lifetime and this shows less noise than the winter daily maximum precipitation originating from an ETC.

Reference

Scaife, A. A., et al. (2014), Skillful long-range prediction of European and North American winters, Geophys. Res. Lett., 41, 2514–2519, doi:10.1002/2014GL059637.

Line 213-214: You write:

"Here we consider the overlap of the shaded areas for each hazard in Fig 3 separately for PC1 and PC2 to determine the relative exposure to multiple ETC hazards at a given location."

Please explain more clearly the method for capturing the overlap and explain what you interpret this overlap to mean.

This has been expanded to: "To determine all the locations where either PC1 or PC2 modify at least one ETC hazard, we overlay the coloured areas for the three hazard regression maps in Figure 3 and plot the net geographical coverage. This is shown in the left column of Figure 5. To determine regions where there are coincident signals in two variables for either PC1 or PC2, we identify where any two coloured areas from the regression maps in Fig. 3 coincide at the gridpoint level. This is in the middle column of Figure 5. Finally, to locate regions with altered exposure to all three hazards, we identify the points where the coloured areas from Fig. 3 coincide when all three fields are overlaid. This is the right column of Figure 5."

Line 237: You write:

"… we next consider the overlap between the PC1 and PC2 patterns for each variable separately, …" How do you do this analysis. Explain it clearly.

This has been expanded to: "Many winters show anomalous North Atlantic atmospheric circulation that partly projects onto both PC1 and PC2, so it is possible that at some locations the exposure to ETC hazards will be modulated by both modes of variability. To determine these regions for each hazard type, we follow a similar process to Section 3.2 where the coloured areas from the regression maps in the middle and right columns of Fig. 3 are overlaid along each row. Where the two fields coincide shows the locations where the exposure to the hazard type will be affected by both PC1 and PC2. The resultant locations are shown in Figure 6 for the three hazard types."