Response to Reviewer 2

We thank the reviewer for a thorough reading of our manuscript and for giving the valuable comments that could improve the quality of the manuscript. Our answers to all the points raised on WCD's website are found below written in blue.

1. I wonder how specific you are on differentiating your "footprints". You state that if they are not connected in your analysis region then they are treated as separate. However, what if the situation arises that they are connected outside of the analysis region as part of a larger wind anomaly, how would this work and is this considered?

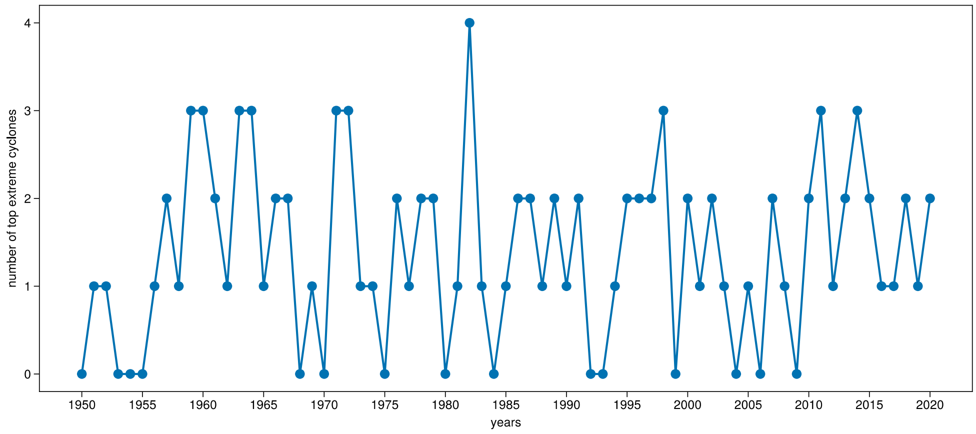
Thank you for this question! If a situation arises so that wind exceedances over the 98th percentiles are forming a connected region with parts outside of the target geographical region, those parts would not be considered. While this choice could potentially influence the ranking of the storms, we made it to be sure that the focus is on the extreme winds over the ocean in the central Atlantic. Extending the eastern boundaries in these cases would bring in the influence of European continent, extending it to the north would include the region under the stronger influence of Greenland. Extending the boundary to the south would start including more systems of tropical origins, while extending it to the west would come closer to the region of cyclogenesis and potentially move the focus away from the region where the peak of the storm track is. Therefore, we have decided to only consider wind exceedances in the target geographical region. We have, although indirectly, at one point considered the area outside of the target region by looking at wind exceedances over Europe for individual cases of some of the strongest storms from top extreme group. However, wind exceedances over Europe for those storms were substantially smaller compared to historical European windstorm events, which further influenced our choice to restrict our analysis to the target region only.
We added a sentence that clarifies this in the Section 3.1.

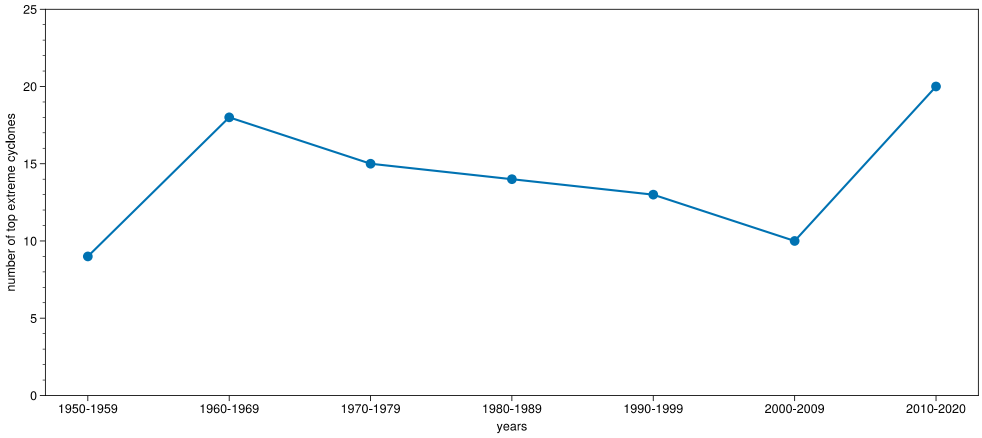
2. Throughout you use ERA5 anomalies from the 1979-2020 climatology, yet your features are identified from 1950-2020. Why this choice? Surely your climatology should match the time period which your events are taken from?

We agree with you and you are absolutely right that climatology used should be the one from 1950-2020. The only reason for using the 1979-2020 climatology was practical since at the time when we performed the analysis, ERA5 data from 1950-1978 was not fully processed. Since those datasets are available now, all the figures where we have previously used 1979-2020 climatology (Figures 1, 3-6) will appear as new figures with 1950-2020 climatology used in a new version of the manuscript. Although did not cause any important quantitave or qualitative differences that could significantly change our previous results or discussion.

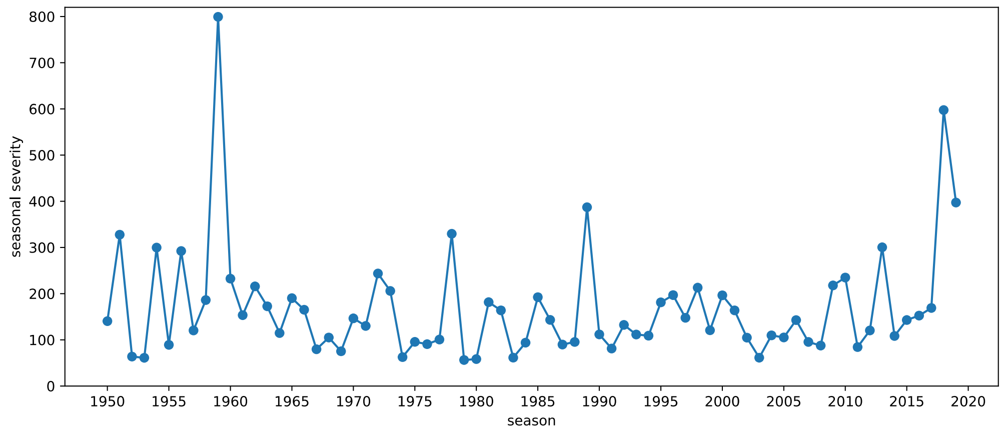
3. When are your top 1% events found in the event data? Do these align with times of historically high EU windstorm activity (1990s) or are they regularly interspersed throughout the historical record. Some information on this would be of interest to the readers of this manuscript.

   Thank you for this question! Figures below show numbers of top 1% of events in each year and in each decade.





As can be seen from the Figures above, top 1% of events seem to be regularly interspersed through the period and there is no apparent trend in their occurrence. One thing that can be noticed is that the year 1999 which had several big windstorms over Europe has zero storms in top 1% strongest storms in the central Atlantic. There also seems to be a lack of the apparent trend when looking at the total seasonal severity over the whole target region (summed value of severity index for all days and all grid cells in the season, no matter if regions are connected or not). This can be seen at the Figure below.



Short information about the things mentioned above will be presented in the new version of the manuscript in the Section 3.2, especially since this question potentially opens a door for further research on the connections between extreme European and central Atlantic windstorms.

4. L290-291 - you talk about how the PV field is representative of Rossby wave breaking composites, does it not make sense to demonstrate this yourself with composites of the RWB field?

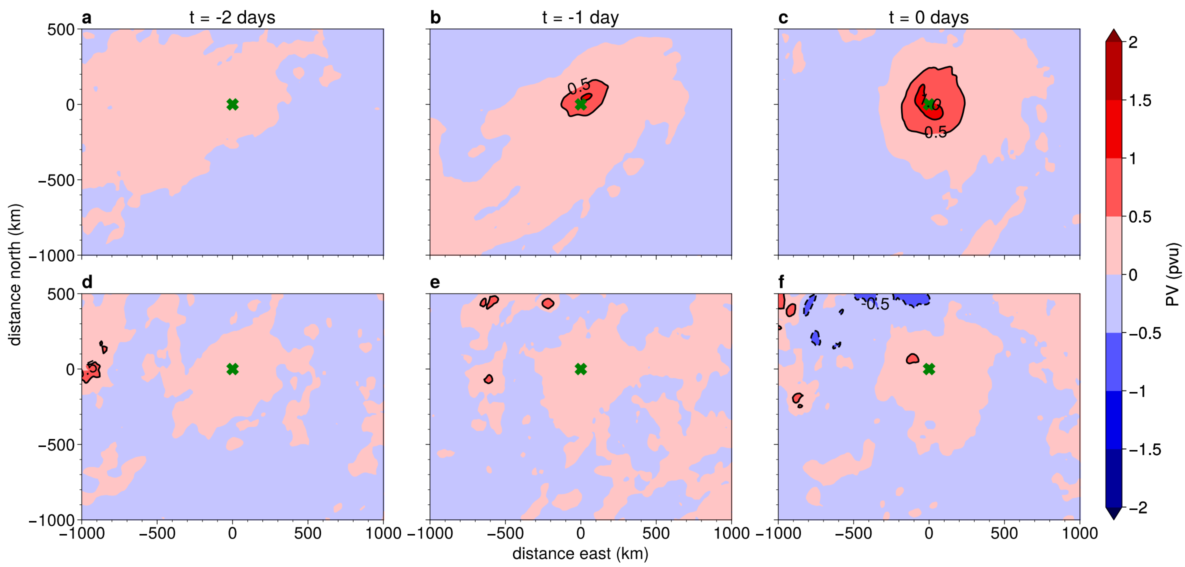
We agree that objective ways of determining whether RWB is associated with these events would be more rigorous (for example the ones used in Wernli and Sprenger, 2007; Barnes and Hartman, 2012; Gomara et al, 2014), but we have chosen not to apply them because of the limited number of cyclones present in our analysis. Objective methods work well when the main interest is analyzing climatology of many wave breaking events and quantifying their characteristics (for example the intensity of RWB). However, since we analyzed a relatively small number of top extremes compared to the broader climatology of objectively identified RWB published in previous studies, our goal was to not to make any quantitative statements. Instead, we relied on qualitatively identifying the ingredient necessary for physical interpretation of RWB (i.e. the overturning of PV gradient) and since we found it to be present, we decided to make a comment about it like was done in some previous similar studies that also did not use objective methods of finding RWB (like Hanley and Caballero, 2012).

Additionally, the focus on a small number of events provides the opportunity to check the PV fields of individual events and subjectively find RWB events. It also gives more confidence that composites of PV field will be representative of RWB.

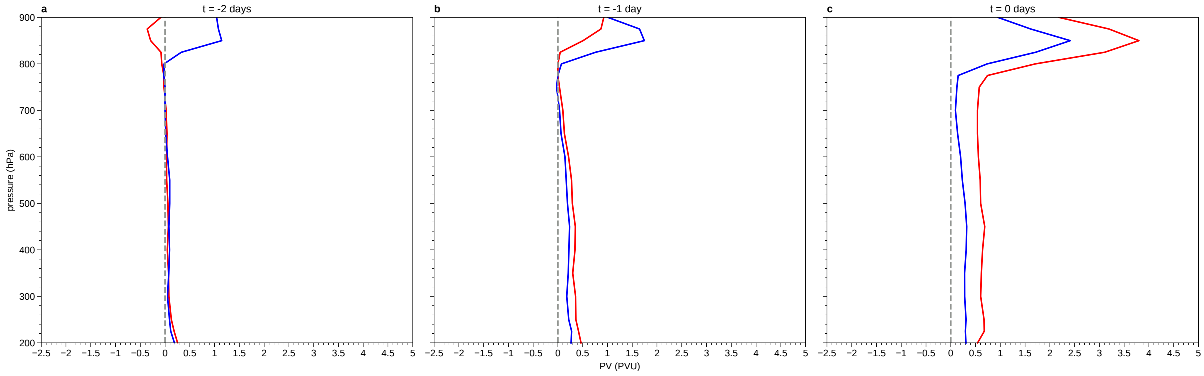
However, since we did not choose to use any objective method to characterize RWB and because identification of RWB events was not the main objective of the analysis, we decided to use the wording that makes that clear (line 237 in the old version of the manuscript: "… structure reminiscent of cyclonic Rossby wave breaking") and restrained from using strong wording in this case.

5. You only show upper-level PV in your composites. It would be good to also see composites of lower-level PV. As you state it is likely that your top1% cyclones are somewhat frontal in nature, and so the lower-level PV anomalies may help strengthen that argument and provide further distinction from your bottom 10% category.

This is a good suggestion! Composites of low-level PV (mean between 650-900 hPa, as for example in Čampa and Wernli, 2012) anomalies centered at the locations of top-extreme and moderate-extreme cyclones can be seen below. Since low-level PV field has more noise than upper-level PV field, the area around the cyclone centers shown is smaller than in the other composite figures in the manuscript. As can be seen, the main difference between the two groups lies in the intensity of the lower-level PV anomaly, with top-extreme cyclones having stronger positive low-level PV anomaly associated with them.



To emphasize that the main difference when it comes to lower-level PV anomalies between the two groups of cyclones is a quantitative difference, the figure below shows the median vertical profile of PV anomalies at levels between 900 and 200 hPa at t=0 days, with the shading showing upper and lower quartiles. Anomalies have been calculated in the area with the radius of 300 km around the cyclone center. The figure below emphasizes that a difference in PV anomalies at t=0 days between the groups stretches down to the surface and is not only confined to the upper-level PV anomalies as the current version of the manuscript might suggest. This finding is also in line with the previous findings that cyclones associated with stronger winds have stronger positive PV anomalies at both lower- and upper-levels (Čampa and Wernli, 2012). We plan to include the figure below to a supplementary material with a short discussion around it in the new version of the manuscript.



6. L145-148 – In the bottom 10% category you have 117 events, which is very similar in number to those from the top 1%. How is this the case considering there should be 10x the number of events? Is this because most of them are not associated with ETCs or TCs? Please clarify this in the text

Thank you for this comment. While the number of days in the bottom 10% category is indeed 10x the number of days in top 1%, the events have the similar number because of the extra condition added when identifying moderate extreme events. For them, an additional criterion that cyclones existed for at least 2 days before they caused footprint of wind exceedances in the target region was added. Because of this, there is a decrease in number of moderate events. This decrease is perhaps not a surprise when we consider that around 40% of all cyclones have a **total** lifetime shorter than 2 days (Neu et al. 2013) and that this condition further requires that cyclones had their cyclogenesis at least 2 days before they came into the region where the bulk of the North Atlantic storm track is. The purpose of this added condition was to make comparison between top-extremes and moderate extremes more meaningful so that we could make the same composites centered at the same time steps (as top extremes typically had their cyclogenesis 2 days prior to the extreme 10-m wind events). This criterion was mentioned in the old version of the manuscript (L145-147), however we agree that it is not clear that this has caused lower number of the events in moderate extreme group. We will, therefore, clarify this in the new version of the manuscript in second to last paragraph in Section 3.2.

7. L136 - are all of your top 1% events associated with ETCs or TCs? Or did you have to discard some that did not

When we were identifying top 1% of the events, all of them could be eventually associated with ECTs or TCs. We were always able to find a MSLP minima connected to the 10 m wind speed maxima and track it back in time. When we found that tracks match those from HURDAT dataset, we have associated them with tropical to extratropical transitions and all the rest of the events were put in the top 1% category. A sentence in third to last paragraph in Section 3.2 was added to make this clear.

- Equation 1: You need a term to state that D is only calculated for gridpoints where v_i>v_98i

  Thank you – a term is added.

- L90 - is the climatology used to create the 98th percentile just Oct-Mar or is this annual?

  It is the extended winter (Oct-March) climatology from 1950-2020 in this case. The clarification addressing this is added at this place in the manuscript.

- Section 3.2 - i'm a little confused as to what time you used for the tracking (6hour or 1hour). This section could do with some re-writing to clarify this.

  Tracks used for top-extremes are 1-hourly tracks, while those used for moderate extremes are 6-hourly. New version of the manuscript has made this explicit in Section 3.2.

- L111 - proxy to relative vorticity - please change

Thank you – done!

- L161 - you have not yet shown that the surface MSLP decreases in this timeframe

  That is a good point, we have changed this sentence to address this.

- L163 - Most cyclones (again you have not yet shown anything for your cyclone analysis set)

  Thank you – changed.

- L216-218 - i would move this paragraph up, or at least talk about the jet streaks first before you start discussing the structure of the PV anomalies

  We have moved this paragraph up and changed the order in which we talk about jet streaks and the PV anomalies.

References:

Barnes, E.A. and Hartmann, D.L., 2012. Detection of Rossby wave breaking and its response to shifts of the midlatitude jet with climate change. *Journal of Geophysical Research: Atmospheres*, *117*(D9).

Čampa, J. and Wernli, H., 2012. A PV perspective on the vertical structure of mature midlatitude cyclones in the Northern Hemisphere. *Journal of the atmospheric sciences*, *69*(2), pp.725-740.

Gómara, I., Pinto, J.G., Woollings, T., Masato, G., Zurita-Gotor, P. and Rodríguez-Fonseca, B., 2014. Rossby wave-breaking analysis of explosive cyclones in the Euro-Atlantic sector. *Quarterly Journal of the Royal Meteorological Society*, *140*(680), pp.738-753.

Neu, U., Akperov, M.G., Bellenbaum, N., Benestad, R., Blender, R., Caballero, R., Cocozza, A., Dacre, H.F., Feng, Y., Fraedrich, K. and Grieger, J., 2013. IMILAST: A community effort to intercompare extratropical cyclone detection and tracking algorithms. *Bulletin of the American Meteorological Society*, *94*(4), pp.529-547.

Wernli, H. and Sprenger, M., 2007. Identification and ERA-15 climatology of potential vorticity streamers and cutoffs near the extratropical tropopause. *Journal of the atmospheric sciences*, *64*(5), pp.1569-1586.