Review of the manuscript
Characteristics and dynamics of extreme winters in the Barents Sea in a changing climate
By Katharina Hartmuth, Heini Wernli, and Lukas Papritz (WCD-2024-878)

The aim of the manuscript is to provide a comprehensive analysis of the characteristics and dynamics of extreme winters over the Barents Sea (BS) for both present-day and future conditions, based on large ensembles of climate simulations with the model CESM1. In particular, is study aims to identify the most crucial surface parameters for characterizing extreme winters over the BS, to distinguish different classes (clusters) of extreme winters over the BS and to examine their sub-seasonal evolution and the role of synoptic-scale systems (cyclones, anticyclones, cold air outbreaks (CAO) in the development of these clusters of extreme seasons. Finally, the impact of climate change on these characteristics is investigated. The authors concluded that in the future, anomalous atmospheric circulation will play a more important role than anomalous boundary conditions in the formation of extreme winters.

Given that the BS is both, a hot spot of the current Arctic climate change, exhibiting the strongest temperature amplification and sea ice retreat, and an important region for initiating processes underlying Arctic-midlatitude linkages, particularly the stratospheric pathway in winter, the topic of this study is timely and relevant.

The manuscript forms part of a series of papers on the topic of Arctic extreme seasons (Hartmuth et al., WCD 2022, Hartmuth et al., GRL, 2023). It extends those analyses with an examination of future changes of the characteristics of extreme winter seasons over the BS.

The applied methods comprise a PCA analysis and a cluster analysis, which are not commonly employed in climate studies. In my view, this combination is well suited to the aims of this study and I find it highly intriguing. Many details of the methods and the data-preprocessing can be found in the aformentioned previous papers, while this manuscript provides only a brief overview. This approach may be understandable, but it does present certain challenges for the reader, who may be required to consult the previous papers in order to gain a full understanding of the methods employed. It would be beneficial to expand the description of the methods (see major comment 2).

The manuscript is well-structured, but it is lengthy, and in some parts provides too much details. This makes it not easy to follow the storyline of the paper and to get the main messages.

Overall, the submitted manuscript needs careful and major revision.

Major comments:

(1) The entire manuscript should be streamlined to allow for a clearer storyline and clearer main messages. I recommend to shorten in particular the introduction, section 4.2/5.2, and the conclusions.

(2) Ads i previously stated, i recommend to expand the methods description, in order to allow for understanding the methods without the need to read the earlier publications. It is of particular importance to provide a detailed description of the data pre-processing employed for the calculation of the climatological background and, subsequently, the anomalies. This is because the results often depend on the manner in which the climatological background is calculated.

Since PCA in climate studies is mostly used in the S-mode (data matrix n x N with n number of stations/gridpoints and N number of timesteps and component score matrix r x N, r number of PCs) it would be beneficial to mention that here PCA is applied in P-mode (data matrix n x N with n number of parameters and N number of timesteps and component score matrix r x N, r number of PCs) (see overview table 9 in Richman,1986, Int. J. Climatology, 6, 293-335). Furthermore, I would like to ask, what is the advantage of the proposed cluster method over standard approaches like e.g. K-means clustering. Have the authors tried out such methods as well?

(3) Section 4.2/5.2: The meaning of the title "Substructure" is not apparent without reading the subsection. In summary, these subsections showing the evolution of two specific extreme winters for each cluster demonstrating sub-seasonal variability. I wonder if this information is really needed, or if accumulated information as presented in Figs. 4 and 7 is sufficient to characterize the relationship between the characteristics of the extreme winters in each cluster and synoptic-scale weather events.

Minor comments:

(1) Abstract: Should be improved. L19: "substructure" has to be explained.

(2) Introduction, L26-33: In my view, BS as hot spot of Arctic amplification should be mentioned.

(3) Introduction, L48-58: If the authors want to keep this detailed description of Arctic-midlatitude linkages, they have to be more precise in explaining tropospheric and stratospheric pathways, and the role of changes in wave activity (L54).

(4) Introduction, L69-70: "reduction in local baroclinicity following the strong sea ice retreat" In my view, this is not fully clear, since baroclinicity (e.g. expressed in term of max. Eady growth rate) is determind by vertical wind shear AND static stability.

(5) L147-151: Please explain, why you authors have used this very specific definition of BS region? How this compares to the standard definition in terms of geographical coordinates?

(6) L184: I am sorry, but I do not understand the return period of 40 years (with 50 events in an overall ensemble of 1050 simulated winters).

(7) L256: Could you provide the values of correlation between the different precursors and their changes between present day and future?

(8) L263-266: Is this the only reason for the nearly unchanged correlation between the precursor variables?

(9) L269-273: In my view, via a projection it should possible to show the PCA results for S2000 and S2100 in the same state spcae to see the changes more clearly. Did you try such an approach? Why did you decide against such an approach?

(10) Fig. 2: In my view, the inclusion of SLP anomaly plots would help for the characterization of the different clusters. Please, provide these plots as well.

(11) L405: I do not see a dipole in f_CAO*, it is strongly positive over the BS area.

(12) L581-582: "while T extremes feature patterns that favor anomalous horizontal transport of warm and cold air, respectively, towards BS."
Kind of hen-and-egg problem, better to explain it this way: patterns for T extremes are related with anomalous horizontal transport of warm and cold air, respectively, towards BS.