Review of WCD-2021-18, Revision 2
WCD-2021-18

Title: Identification, characteristics, and dynamics of Arctic extreme seasons

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General comments:
The authors evaluate the atmospheric conditions during anomalously extreme seasons in the Arctic. This is performed using a regional principal component (PC) analysis (PCA) from ERA5 data of the first two PCs of all seasons from 1979-2018. The PCA uses six key surface variables and divided spatially into 9 Arctic sub-regions subjectively chosen based on climatological sea ice conditions in either the Nordic Seas, Kara and Barents Seas, and the rest of the Arctic. Results identify 2-3 extreme seasons for each season and in each sub-region. The PCA applied here provides a quantification of how anomalous a season is relative to another season, which variables contribute most to the extreme conditions of the respective season, and how consistent those conditions are during those particular seasons. The authors then choose two extreme or anomalous seasons in the Kara-Barents sea during winter (DJF) and one extreme DJF season over the "High Arctic" to further investigate the synoptic weather conditions that were occurring. The chosen seasons are picked based on their orthogonal, yet anomalous or extreme, projections onto the PCs, as well as their diverse processes.

This research nicely demonstrates how PCs can be used to identify seasonal anomalies and extremes in certain regions of the Arctic. It furthermore demonstrates how to use that information to provide an expectation of how an extreme season was characterized with regard to of one of the six variables and how consistent those conditions were. It is certainly a notable method to identify extreme seasons that might be worth analyzing in further detail at shorter time and space scales if desired. I thank the authors for considering and addressing my major concerns from the previous version. I note that in the previous version of the manuscript, the sign convention for the surface energy budget was not stated (and I thank the authors for adding that in the latest revision), which has now allowed me to comment on the surface energy budget in this version with the new insight. Overall the arguments are much clearer and this manuscript will make a positive contribution and be published once a few remaining issues are addressed. Specifically:

1) I appreciate that the authors added correlation coefficient values and respective p-values in Tables S1 and S2. The corresponding text still needs some refinement, however. Since they are performing a statistical significance test, they can choose a p-value (say 0.05 or 0.01) to be a threshold as a "statistically significant correlation" a priori. This would clarify some of the statements, as sometimes I am not sure whether they mean that the correlation coefficient value is high (subjective) or whether they mean that the p value is low (objective since the correlation in that case is statistically significant). For example, on line 243, do they mean there is no *statistically significant* correlation in the summer? That would make most sense to me, given the high p-values. The magnitudes of the coefficients are also relatively low, but it is subjective to make conclusions based off that, alone. Generally, the lower p-values correspond to the higher coefficients, so it shouldn't change most of the conclusions to refine the wording whenever the word "correlation" is used.

2) The story for the DJF 2011/12 case (Section 5.1) is very interesting but does not quite seem to make complete sense to me as described here. It is argued that the consistently warm temperatures are because of the repeated passage of cyclones from the Nordic Seas.

Yet, the authors point out that overall, cyclone frequency was below climatology, and there were frequent blocking episodes. However, precipitation was one of the relatively lowest seasons over KBM with perhaps a few episodic precipitation events (i.e., Fig. 5h). Of course, blocking episodes favor warmer temperatures, and SLP was higher than average for much of the time when temperatures were above average and when there was blocking (Figure 9a,e, and colormaps). But then how does the consistently lower SIC come into the story? Note that the September 2011 sea ice extent was the second lowest since 1979 up to this point, and much of this was in the Kara and Barents Seas, so there could very well have been a new surface forcing in that region. Indeed it seems at a glance like this may not have an impact in DJF, because of the strongly positive and consistent $\overline{E_s^*}$ (Fig. 5l) and $\overline{H_S^*}$ (Figure 7b). Presumably cloud cover was anomalously low, though this could easily be checked by looking at whether $\overline{R_L^*}$ has the same sign as $\overline{E_s^*}$ and $\overline{H_S^*}$. Perhaps though, there was preconditioning in the autumn (October - November), which if there was anomalously more open water instead of ice, then there could be anomalously high upward sensible heat fluxes, which lead to warmer temperatures and higher tropospheric thicknesses by the time DJF started leading to forcings that favored patterns for blocking. Can this be ruled out? Figure 1 shows that in the two months before DJF 2011/2012, surface skin temperature, 2-m air temperature, and 850 hPa air temperature anomalies all had similar patterns to DJF in the lower troposphere before the blocking pattern arose, supporting a preconditioning by the surface conditions.

3) In the DJF 2016/17 case, is it that an extreme E_s^* anomaly occurs when there is reduced SIC ***and*** a marine CAO? The cyclones reduce the SIC in KBM, and the passage of the cyclone is then followed by a CAO. For example, the extreme negative anomaly in E_s^* between days 30-35 (Figure 10b). There was a cyclone around day 25 (Figure 10e, Figure S7) that reduced SIC. After the cyclone passed, there was a strong CAO at nearly the same time as the negative E_s^* (Compare Figure 10b with Figure 10 CAO heatmap) and negative T_{2m}^* (Figure 10a). Right now, the wording of the text in lines 449-462 makes it seem like the CAO is just an additional factor, but it seems like it may be the critical factor in order to lead to the overall magnitude/rank in $\overline{E_s^*}$ since lower sea ice alone would not necessarily do so. Also, the cyclone paths may be important such that there are frontal passages that promote CAOs in their wake in the right regions. Furthermore, if this is the story, I might consider choosing one of these marine CAO cases to highlight in Figure 11 instead of the current warm temperature anomaly case, esp. since overall $\overline{T_{2m}^*}$ was not ranked as highly (Table 2). I think this then flows better for the text on lines 481-486 where SIC, T_{2m}^*, marine CAOs, and E_s^* are readdressed and furthermore when preconditioning is discussed thereafter on lines 488-506.

Other specific comments:

1) Line 19: normal → either "average" or "typical"

2) Line 88: Recent studies emphasized the *importance* of polar anticyclones and blocking events in the High Arctic ***for what***? Insert into sentence.

3) Lines 90-93: Burt et al. (2016) also discuss this positive warming feedback, and additionally show a possible regional implication.

4) Line 145: Since the CAOs here can only be identified over water, insert "marine" in front of "cold air outbreaks."

5) Lines 299-300: How exactly can we see from Figures 5 and 6 that the driest years have non-zero precipitation amounts? What does it mean that it is less evident? Is this just a result that is not shown and therefore not evident from the plots?

6) Lines 346-347: In sub-regions ARI and ARM, I do not understand why the positive correlation between $\overline{R_L^*}$ and $\overline{T_{2m}^*}$ emphasizes the importance of clouds. For example, in the summer, when it is cloudier, it is cooler due to less shortwave radiation reaching the surface, so $\overline{T_{2m}^*}$ is more negative. Clouds increase the downwelling longwave radiation, thus making $\overline{R_L^*}$ more positive according to the sign convention.

7) Line 369: continuous → consistent

8) Line 371: What does "equally strong" mean when comparing two different variables?

9) Line 395: Can't we see that the largest $\overline{T_{2m}^*}$ over the 39-year period from Figure 5b,d instead of Figure 7b,d, where we can only see the principal component values, which are a combination of variables, correct?

10) Line 401: Insert T_{2m}^* in front of "values" to make it less ambiguous exactly what values are being referred to, esp. since $\overline{T_{2m}^*}$ was just referred to beforehand.

11) Line 407: What is meant by "strongly correlated" exactly? Is there a correlation coefficient being referred to or is this meant to be a visual comparison between panels a and b in Figure 9?

12) Line 532: How much of the warming was caused by subsidence vs. horizontal advection? The trajectories show descending air parcels, but I can not see how much warming would be caused by that in this case.

13) Lines 539-543: Up until this point, preconditioning referred to the state of the sea ice at the beginning of the season in question (i.e., Question 4 on line 117). The discussion here and Figure 13 suggests a different (yearly) time scale, i.e., that the sea ice state from previous winters could be a preconditioning for the current winter. The shorter-term preconditioning may be more important in the 2011/2012 case, given that the September 2011 sea ice extent minimum was the second lowest extent on record up to that point.

14) Lines 666-667: Is the CESM large ensemble capable of representing the synoptic processes described in this paper?

Technical corrections:

1) Line 372: don't → do not

2) Line 401: Remove "about"

3) Line 405: we ↔ here

4) Line 488: Remove "also" before "preconditioning"

5) Line 545: Remove "want to"

References

Burt, M. A., D. A. Randall, and M. D. Branson, 2016: Dark warming. *J. Climate*, **29 (2)**, 705–719.

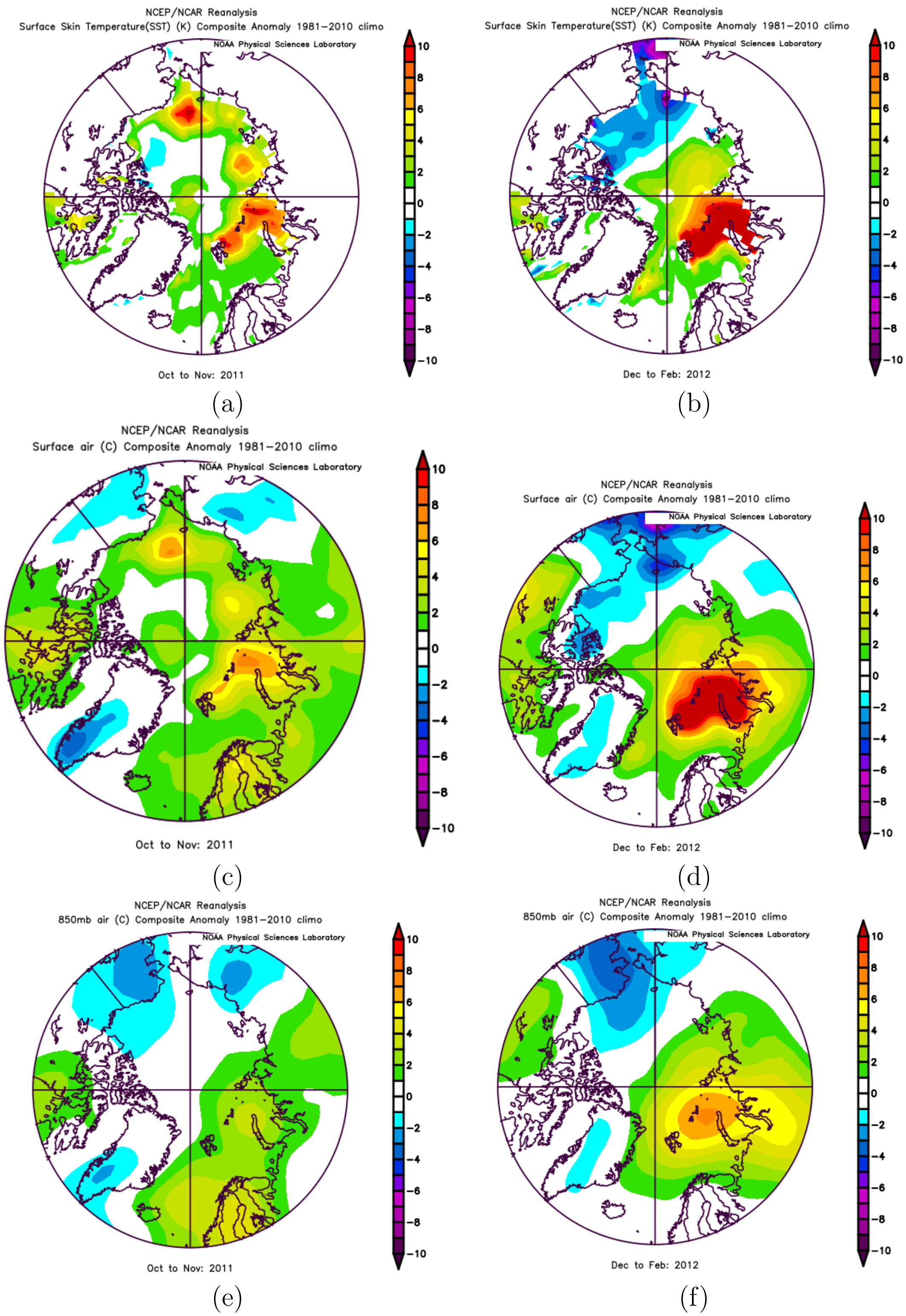

FIG. 1. Anomalies in monthly mean (a), (c), (e) October-November 2011 and (b), (d), (f) December - February 2011/2012 (a)-(b) surface skin temperature, (c)-(d) 2-m air temperature, and (e)-(f) 850 hPa air temperature. NCEP/NCAR reanalysis data are freely available from https://psl.noaa.gov/cgi-bin/data/composites/printpage.pl.