Answers to second revision.

egusphere-2025-1373

“Summertime Arctic and North Atlantic-Eurasian Circulation Regimes under Climate Change”

By Johannes Müller, Oskar Landgren, and Dörthe Handorf

We would like to express our gratitude to Reviewer 1 for their thorough engagement with our research and active participation in the discussion. We would also like to thank Reviewer 2 for accepting our revised revision, for it being a substantial workload. Both reviewers and also we agreed that this was an imperative requirement. The author's comments are indicated in black text and the responses to these comments are indicated in green text. If any alterations are made to the revised manuscript, the reader is explicitly informed.

1. I do agree with the authors that the use of the same reference space allows for a better comparison between models and reanalysis. However, I do not see how the quantization error being smaller in CMIP6 models than in ERA5 justifies the use of pseudo-PCs. (In short, I do not agree with reviewer 2.) To my understanding the quantization error gives an indication of the spread around the cluster centre (in pseudo-PC space), which does not necessarily say anything about how well the data is represented. I think that because the ERA5 PCs are not the direction of the most variance for the model it makes sense that mostly the data shows a smaller spread around the cluster centre, as indicated in the attached sketch (last page of PDF, as I can only upload one file) (of course the clustering likely identifies different patterns which could affect the spread for certain regimes).

   This comes down to (by definition) the pseudo-PCs describing less of the variance than the models own PCs. Furthermore, as can also be seen in the sketch, the cluster centres do not necessarily represent the same patterns, as they do not project onto the same location. I would be happy to be convinced otherwise on both points.

To me a reasoning like in Fabiano et al. (2020) would be acceptable, although I do believe some more in-depth discussion of the biases it could introduce would be very valuable. I do not think the quantization error indicates what the authors claim it does and ask them to remove this.

Thank you for the suggestions. We agree that the pseudo-PCs describe less variance than the models own PCs and this might introduce biases in our analysis. We decided on the projection approach following Fabiano et al. (2020, 2021) mainly due to the fact that projection ensures that all calculations are done in the same reference space and allows comparison of regime patterns in a consistent way. Furthermore, Fabiano et al. (2020) investigated the possible effect on 2 metrics (variance ratio and sharpness) they applied to evaluate the regime structure and showed that the results are consistent for both approaches.
Here, we applied the variance ratio to test the consistency between clustering in the pseudo PC- space versus clustering in the models own PC-space. The variance ratio, also called optimal variance ratio, this is the ratio between the mean inter-cluster squared distance and the mean intra-cluster variance (see e.g. Fabiano et al. (2020), equation (2)). The larger the variance ratio, the more clustered are the data, giving compact clusters well apart one from the other.
Fig. R1 shows the variance ratios for K-Means clustering in the pseudo PC-space versus clustering in the models own PC-space for the common model clusters over the North-Atlantic-Eurasian region for the present day period together with the variance ratio for the ERA5 reference clusters. Similar to Fabioano et al. (2020) we found that the model simulations have a lower variance ratio than the reanalysis and are outside the ERA5 variability range. This means that the model regimes tend to be systematically less tightly clustered. Comparing the variance ratios using the models own PC-space and using the Pseudo-PC space revealed indeed a slight increase in the Pseudo-pc space, indicating stronger clustered data (due to less variance described by the Pseudo-PCs). Nonetheless, the difference is not significant and the variability range is similar.

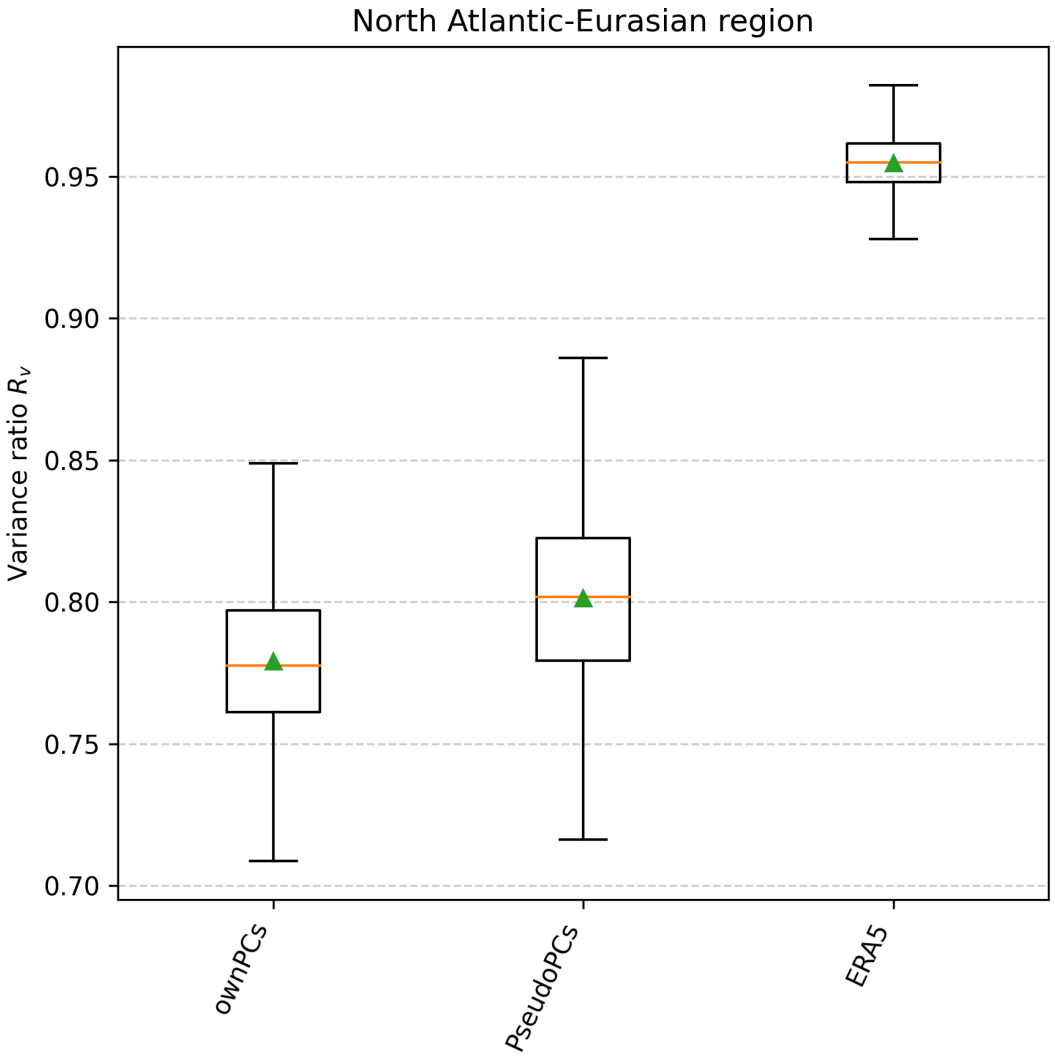

Figure R1: Variance ratio for Common circulation regime data projected onto reference state space (Pseudo PCs) and its own state space (own PCs) as well as ERA5. The box plots refer to the distribution of 15-yr bootstraps (n=1000) of each model and show mean (triangle), median (horizontal line), first and third quartile (boxes) and 10 and 90 percentiles (bars).

In addition, we proved whether the cluster centers obtained with both approaches represent the same patterns. Fig. R2 shows the patterns representing common cluster centers obtained by K-Means clustering in the pseudo PC- space (upper row) the models own PC-space (lower row)over the North-Atlantic-Eurasian region for the present day period, the respective Taylordiagram for this comparison is shown in Fig. R3. The patterns obtained with both approaches are very similar with pattern correlations higher than 0.95.

Both, the analysis of the variance ratio and the evaluation of the cluster center patterns support the applicability of the projected approach for our analysis.

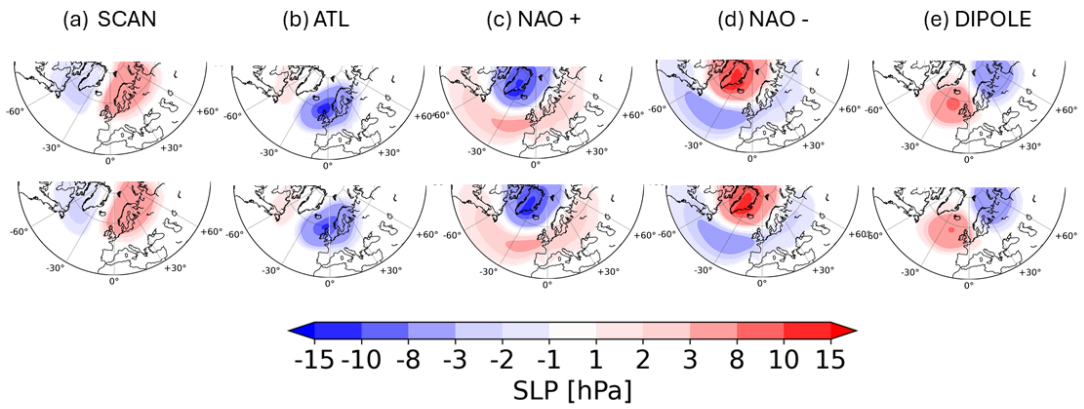

Figure R2: North-Atlantic Eurasian Circulation regime patterns in terms of SLP anomalies for MJJASO, for CMIP6 models in the historical period 1985-2014 obtained with K-Means clustering. Upper row: Common simulated circulation regime approach, with model data projected onto the ERA5 state space, lower row: Common regime approach with state space spanned by common EOFs from climate model data.

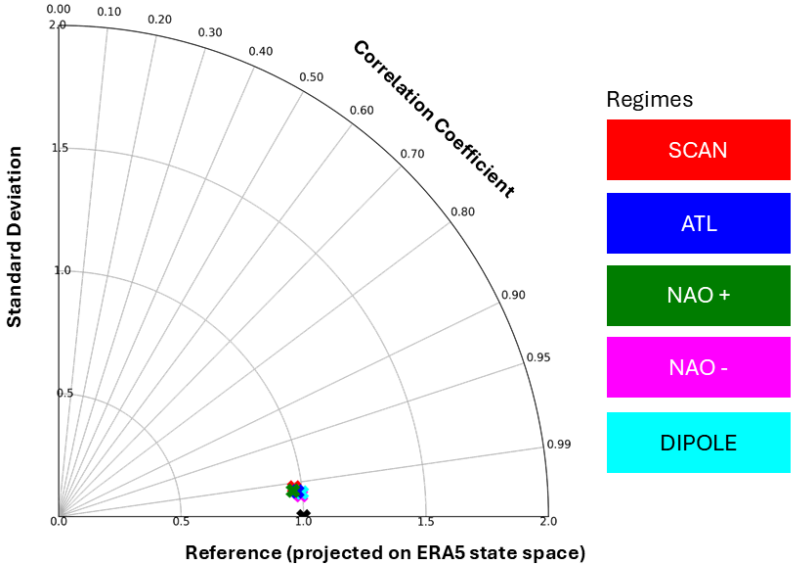

Figure R3: Common regime approach with state space spanned by common EOFs from climate model data compared to the reference of model data projected onto the ERA5 state space for the North-Atlantic Eurasian region.

Old text from L133:

"Projecting the CMIP6 model data onto the ERA5 reference state space ensures that all calculations are performed in the same reference space, enabling consistent comparison of regime patterns.

However, this method requires the model subspace to be contained within the reference space. To prove this, we applied the quantization error proposed by \citet{Quagraine2020}. According to \citet{Quagraine2020}, the quantization error is defined as the mean error of each day's circulation pattern with respect to the reference cluster pattern to which it belongs. If the error in the CMIP6 model patterns is greater than that in the ERA5 patterns, the model subspace is not contained within the reference space spanned by the reanalysis data. Analyses of the quantization errors for the North Atlantic-Eurasian regimes for ERA5 and the CMIP6 historical simulations from 1985 to 2014 obtained using the KME method revealed that, except for two regimes and two or three models respectively, the model patterns have smaller errors than the ERA5 patterns (see Appendix A, Fig.~\ref{fig:qe_ATL}). This justifies the projected approach. A similar conclusion can be drawn for the Arctic regimes: the majority of the CMIP6 patterns have smaller errors than the ERA5 patterns, except for three regimes with three, three and one model, respectively (see Appendix A, Fig.~\ref{fig:qe_arc}). "

New text:
"*Projecting the CMIP6 model data onto the ERA5 reference state space ensures that all calculations are performed in the same reference space, enabling consistent comparison of regime patterns. Nonetheless, the pseudo-PCs describe less variance than the models own PCs and this might introduce biases in our analysis. Following Fabiano et al. (2020) we tested the consistency between clustering in the pseudo PC-space versus clustering in the models own PC-space by analysing the variance ratio, i.e. the ratio between the mean inter-cluster squared distance and the mean intra-cluster variance for K-Means clustering in the pseudo PC-space versus clustering in the models own PC-space for the common model clusters over the North-Atlantic-Eurasian region for the present day period together with the variance ratio for the ERA5 reference clusters (see Appendix A). The model simulations have a lower variance ratio than the ERA5 data and are outside the ERA5 variability range. The variance ratio revealed a slight increase in the Pseudo-PC space, indicating stronger clustered data. Nonetheless, the difference to the variance ratio in the models own PC-space is not significant and the variability range is similar. In addition, we investigated whether the cluster centers obtained with both approaches represent the same patterns (Appendix A) and found very similar patterns with pattern correlations higher than 0.95. Both the analysis of the variance ratio and the evaluation of the cluster center patterns support the applicability of the projected approach for our analysis.*"

Accordingly we have removed the former Appendix A about the quantization error and added a new Appendix A showing and describing the figures above (R1-R3).

2. In addition, it would be valuable to evaluate the different between the methods for the Arctic region in some more detail, e.g. by looking at the difference in regime assignment. Which days are assigned to Cluster 5 by KME, but not by SAN and which regime are they assigned to instead? Based on the patterns I would guess that some days assigned to the Bering-Svalbard dipole or AO- by KME, are assigned to cluster 5 by SAN for example. The different regimes also reflect in the poorer correspondence for the other regime patterns and could help interpret the different results for the future shifts. See also some comments in the PDF.

A: We agree that in fact, the regime assignment may be helpful to understand and confirm the assumptions we made in L393 and L432. In order to do so, we present the overlap between assignment of days between KME and SAN patterns. The rows indicate the KME patterns, respective the columns SAN patterns. This means, that e.g. the first row in Fig.R4: Days assigned to the KME SCAN pattern are in 81.6% of all days also assigned to the SAN SCAN pattern, and only to 5.3% to the NAO+ SAN pattern or 10.3% to the NAO- pattern. Therefore, the sum over the rows is always 100%, the sum over the columns can be higher or lower than 100%. For the North Atlantic-Eurasian as a comparison, days are assigned to the same patterns across both methods in >80% of the total days.

	SCAN	ATL	NAO+	NAO-	DIPOLE
SCAN	81.6	1.4	5.3	10.3	1.4
ATL	4.0	84.6	0.9	9.7	0.9
NAO+	0.5	15.8	79.8	1.4	2.6
NAO-	0.3	0.5	0.4	98.3	0.5
DIPOLE	0.1	4.4	6.3	4.4	84.7

Figure R4: Percentage Overlap Between KME and SAN Patterns (Rows: KME patterns -> Columns: SAN patterns), North Atlantic-Eurasian region.

This is different for the Arctic region, as Bering-Svalbard and especially Cluster 5 show less agreement across both methods. The assumption made in L393 is quantified here. Days, that are assigned to the Bering-Svalbard KME pattern are assigned to Bering-Svalbard SAN with only 48.8% but also to the Cluster 5 SAN with a chance of 35.1% underlining the spatial similarity between Cluster5 SAN and Bering-Svalbard KME. This also supports the statement of Reviewer 1 : Days assigned to Bering- Svalbard and AO- KME have a higher chance to be linked to Cluster 5 SAN. Since this underlines our assumptions, we would decide to keep the L393 and L432.

	Greenland Siberia	Bering Svalbard	AO+	AO-	Cluster 5
Greenland Siberia	77.2	5.2	7.4	2.0	8.1
Bering Svalbard	1.6	48.8	4.0	10.4	35.1
AO+	1.0	27.6	68.2	3.0	0.1
AO-	20.9	1.0	0.1	62.7	15.3
Cluster 5	10.0	7.0	33.0	25.9	24.1

Figure R5: Percentage Overlap Between KME and SAN Patterns (Rows: KME patterns -> Columns: SAN patterns), Arctic region.

We added at L 393: *"(Days, that are assigned to the Bering-Svalbard KME pattern are assigned to Bering-Svalbard SAN with only 48.8% but also to the Cluster 5 SAN with a chance of 35.1% underlining the spatial similarity between Cluster 5 SAN and Bering-Svalbard KME)."*

3. Lastly, the discussion on the occurrence/persistence can be improved. An increase in occurrence can be due either to a regime lasting longer and/or to it occurring more often. These are different dynamical responses. The change in persistence can illuminate which of the two (or both) is the case. It would be good if this is clarified in the discussions on this.

We agree and thank you for this statement. L 360-364 is changed from
"Most of the results are supported by the findings analysing the persistence, underlining the strong correlation between both metrics for the North Atlantic-Eurasian region. This can be also made for the wind composites changes: regimes associated with a northward shifted jet stream are simulated to occur more often and to be more persistent, while patterns linked to a southward shifted jetstream are projected to occur less often under strong global warming"
to
" *Most of the results are in line with the findings regarding the persistence. Overall we found a high correspondence between future changes in occurrence and persistence. The analyses of the related zonal wind composites revealed that regimes associated with a northward shifted jet stream are simulated to occur more often and to be more persistent, while patterns linked to a southward shifted jet stream occur less often under strong global warming.* "
Additionally we added text, see comment L482 and L504.
We also rewrote at L508/509: "In the Arctic region, the changes in frequency and persistence showed less agreement between the two methods and across both metrics than in the North Atlantic-Eurasian region." with
"In the Arctic region, the changes in frequency and persistence showed less agreement between the two methods and across both metrics than in the North Atlantic-Eurasian region. In contrast to the North Atlantic-Eurasian domain, where we detected a correspondence between occurrence and persistence changes for all

regimes, in the Arctic region this correspondence is only found for the AO- regime." after L509.

Also the introduction of the persistence at L339
"The analysis of persistence changes provides additional support for this result for the North Atlantic-Eurasian region, as the variations in persistence corresponds to the shifts in frequency as shown in Fig.7" is changed into
"*The changes in frequency of occurrence may arise from two different sources: change in how often events occur or for how long they persist. The latter is analysed in the following for the North Atlantic-Eurasian region, shown in Fig. 7*"

Regarding the Atlantic region, additional the following sentences have been added*:*
L344:
", suggesting that the future changes are due to the regimes becoming less persistent as well as the events to occur less often in the future."
L348:
from
"whereas, NAO+ and NAO- do not exhibit a corresponding significant change." to
"By contrast NAO+ and NAO- do not exhibit a corresponding significant change, meaning the change in frequency of occurrence for the NAO patterns may be due to both: a change in persistence of the regimes as well as the events to occur more/less often in general."
L349: replaced "and" with *"for"*
Regarding the Arctic region, additional the following sentence have been added:
L475: "robust" has been changed to *"corresponding"*.
L479:
", meaning the change in frequency of occurrence for the Bering-Svalbard Dipole may be due to the event occurring less often in the future rather than a decreasing persistence."
L482:
" The changes in frequency of occurrence regarding the AO+ pattern predicted by both patterns is underlined by KME findings but not regarding the SAN method, where the change in persistence under future emissions is almost zero and non-significant." to
"*Only for the KME method the changes in frequency of occurrence of the AO+ pattern are consistent with the future persistence changes, where the change in persistence is almost zero and non-significant. This finding indicates that the occurrence of shorter AO+ events may be more prevalent regarding the SAN method.*"

At L489 "connection" has been replaced by "*correspondence*".

L546: added *"This means for the Arctic region that if a pattern increases in its frequency of occurrence, it is rather due to the event to occur more often, and vice versa for a decrease. ".*

Comments from pdf:

L114 What is substantial? You specify later, so no need to mention here.
In this paragraph, the EOF analysis is shortly introduced to the reader, for which substantial is unspecified but in our view helpful to understand the sense of the algorithm.
L116 space
corrected

L121 What do you mean by stable?
We would like to refer to Figure R4 (from previous answers to the reviewer 2, page 5 in .pdf file),
where it is shown, that less EOFs may results in different clusters, since they represent a smaller variance of the data, the patterns alter depending on using 5 or 6 EOFs and are therefore called unstable in our case. Still, stable is not very precise phrasing and rewrote to unchanged patterns:
L121 changed from "Moreover,we found a stable spatial structure of the regimes obtained with K-Means clustering (KME) based on ERA5 SLP data only when retaining 6 or more EOFs (explained variance larger than 52 and 45%, respectively) for the North Atlantic-Eurasian region and for the Arctic region." to
" *Moreover, we found that the spatial structure of the regimes obtained with K-Means clustering (KME) based on ERA5 SLP data became unchanged only when retaining 6 or more EOFs (explained variance larger than 52 % and 45 %, respectively) for the North Atlantic–Eurasian region and the Arctic region."*

L169 Suggest Rewriting
The sentence "Instead of performing a common EOF analysis and obtaining common PCs as described e.g. in Benestad (2023), here the common climate model data are projected onto the ten-dimensional reference state space, determined from the ERA5 data, resulting in ten common Pseudo-PCs." has been rewritten to *"Instead of performing a common EOF analysis to derive shared principal components as described, for example, in Benestad (2023), the common climate model data are projected onto the ten-dimensional reference state space defined from the ERA5 data. This projection yields ten common pseudo-principal components (Pseudo-PCs)."*
L197 ve
corrected

L202 They consider jet regimes, i.e. a completely different reference space, which I don't think is comparable to your approach.
We removed the citation here.

L227 Explain that the + and - mean strong/weak.
Corrected: Added: The predictors are accompanied with +/- representing a strong/weak Barents-Kara Sea Warming or Arctic Amplification.
Added in L 226: "... a considerable proportion of the variability in the surface climate response to global warming in the Arctic during the extended summer season is linked to two *predictors*; …"
L301 f
corrected

L301 I do still wonder whether this would change if you e.g. include more PCs, capturing more of the PCs.
We did not investigate how the frequency biases would change if we enhanced the dimension of our reduced state space beyond 10. In our previous response to Reviewer 1, we demonstrated that the spatial structure of the regimes obtained using K-means clustering remained unchanged when 6 or more EOFs were retained. Based on this, we would expect the frequencies of occurrence for both approaches, and hence the respective frequency biases, to remain unchanged.

L331 Which is in line with most literature on the annual mean picture (https://www.sciencedirect.com/science/article/pii/B9780128215753000153#bib5), a seasonal view is given in e.g. https://journals.ametsoc.org/view/journals/atsc/71/7/jas-d-13-0325.1.xml .
This one could also be relevant:
https://journals.ametsoc.org/view/journals/clim/26/18/jcli-d-12-00536.1.xml
Although this is discussed in the Discussion and Outlook RQ1 at L547-551 we agree that the comparison with the literature makes sense in here. We added the provided literature:
L331 we changed "The NAO+ pattern is linked to a tilted, polewards shifted Atlantic jet structure, thus this results
suggests the jet will be shifted northwards under strong global warming" into
"The NAO+ pattern is linked to a tilted, polewards shifted Atlantic jet structure, thus this results suggests the jet will be shifted northwards under strong global warming in the season from May to October, which is concurrent with the changes from June to August shown in Simpson et al. (2014) and the annual mean in Stendel et al. (2021)."

Also, we added the Simpson et al. (2014) paper analysing the seasonal changes into the Discussion and Outlook RQ1 after L551: "*The changes in the extended summer season from May to October are also in line with the northward-shifted Atlantic jet structure found in Simpson et al. (2014) for summer (June to August) and autumn (September to November).*"

L360 You just discussed both occurrence and persistence results, so this formulation confuses me. I'd say the results are in line and leave it at that.,

Here we would like to refer to comment 3.

L360 correspondence (Have you computed the correlation over the models?)

Here we would like to refer to comment 3.

L393 What do you mean by this? The different patterns reflect in the days assigned differently. Which patterns are assigned to 5 in SAN, but not in KME? Which regime do they belong to following the other method?

This is shown in Fig. R5.

L412 , but the 5th cluster shows substantial differences.

corrected

L416 To me this is not evident from what is mentioned before, please clarify,

The shown standard deviation is displaying the spatial standard deviation. Thus a high standard deviation means the anomalies increase in their magnitude (positive or negative). Therefore we agree, it is not evident from the Taylor plot itself and rewrote the sentence from " it is evident that the amplitude of the AO+ pattern is simulated to increase under strong global warming while its spatial correlation with the historical pattern remains above 0.9." into "*..., justifies the application of the projected approach for analysing changes in regime occurrence frequencies between the historical and future periods for the Arctic region."*

L431 and a

corrected

L432 Hypothesis? Also, you can check this by looking at the mean pattern of days that are assigned differently by the two methods.

Please refer to Comment 2

L433 Unclear what you want to say here.

We agree and the sentence is changed from "This aligns their projection to occur less frequent in the future." to "*A decrease in the frequency of low pressure events*

in this area therefore shows up as a negative frequency change in Bering-Svalbard dipole for KME but Cluster 5 in SAN."

L458 Again, also for SAN?

The data for the SAN method is included below in Figure R6:

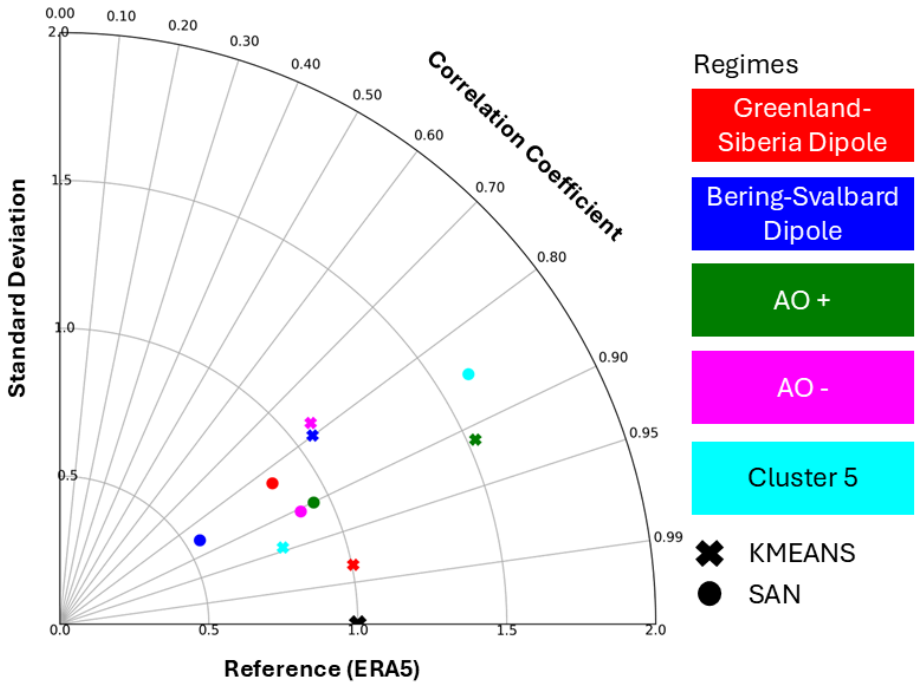

Figure R6: Taylor diagram comparing the future common simulated regimes for the CMIP6 ensemble for SSP5-8.5 and the period 2070–2099 to the corresponding reference regimes from ERA5 reanalysis in the historical period (1985–2014), for the Arctic region. Spatial regime patterns determined with K-Means clustering (crosses) and SAN clustering (circle).

Also for the NAE region:

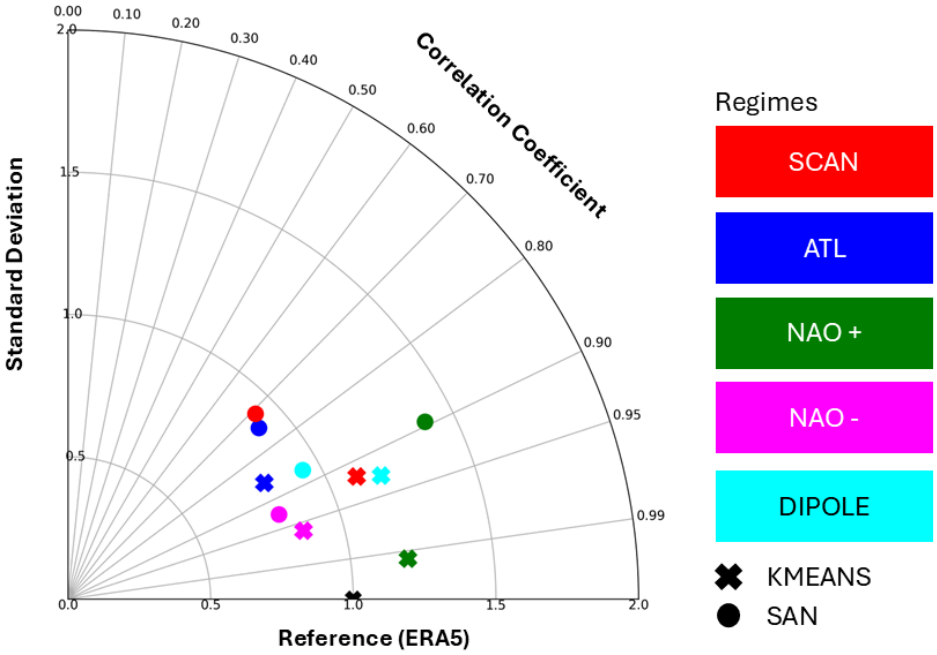

Figure R7: Taylor diagram comparing the future common simulated regimes for the CMIP6 ensemble for SSP5-8.5 and the period 2070–2099 to the corresponding reference regimes from ERA5 reanalysis in the historical period (1985–2014), for the North Atlantic-Eurasian region. Spatial regime patterns determined with K-Means clustering (crosses) and SAN clustering (circle).

We also included them into the manuscript. We rewrote the caption for Figure 4 (NAE region): "*Taylor diagram comparing the future common simulated regimes for the CMIP6 ensemble for SSP5-8.5 and the period 2070–2099 to the corresponding reference regimes from ERA5 reanalysis in the historical period (1985–2014), for the North Atlantic-Eurasian region. Spatial regime patterns determined with K-Means clustering represented as crosses. SANDRA patterns are indicated by circles.*"

We also removed at L284 the description from " In section 3.2 two different methods to calculate circulation regimes within the KME framework for the simulation models were presented: the projected approach and the simulation circulation regime approach. The simulated common circulation regimes for the extended boreal summer season, revealing the joint regimes for the whole ensemble of climate models for the future period, …" to

"In section 3.2 two different methods to calculate circulation regimes for the model simulations were presented: the projected approach and the simulation circulation regime approach.

The simulated common circulation regimes for the extended boreal summer season for the future period, revealing the joint regimes for the whole ensemble of climate models,..."

And for Figure 10:

"Taylor diagram comparing the future common simulated regimes for the CMIP6 ensemble for SSP5-8.5 and the period 2070–2099 to the corresponding reference regimes from ERA5 reanalysis in the historical period (1985–2014), for the Arctic region. Spatial regime patterns determined with K-Means clustering are represented as crosses. SANDRA patterns are shown as circles."
Due to the new Figures we changed the description for Figure 4 from "The calculated common simulated circulation regimes in the future period exhibit high spatial correlation coefficients with the reference circulation regimes from the ERA5 reanalysis data in the historical period. The correlation coefficients reach values above 0.85 for all five regimes and the standard deviations of the common simulated circulation regimes are found to be in close proximity to the reference values between 0.8 and 1.2. " to
"*The calculated common simulated circulation regimes in the future period exhibit high spatial correlation coefficients with the ERA5 reference circulation regimes. The correlation coefficients reach values above 0.85 for KME regimes and above 0.7 for SAN patterns and the standard deviations of the common simulated circulation regimes are found to be between 0.8 and 1.4 compared to the normalized reference standard deviation of 1. "*

Due to the new Figures we changed the description for Figure 10 from " Based on the arguments in Section 4.1, the findings from the box plot in Fig. 5, and the relatively small changes in circulation regime structure under the strong SSP5-8.5 scenario compared to the reference historical ERA5 regimes (with correlation coefficients above 0.78 in Fig. \ref{fig:Figure 10}), the amplitudes of the AO+ anomaly pattern are simulated to increase due to the standard deviation above 1.5. The spatial correlation compared to the historical pattern remains above 0.9. Therefore, the projected approach is applied to analyse changes in regime occurrence frequencies between the historical and future periods for the Arctic region." to
"*In Fig. 10 the Taylor diagram comparing the circulation regime structure changes under the strong SSP5-8.5 scenario compared to the reference historical ERA5 regimes for KME and SAN algorithm is shown. The standard deviations differ from the reference (normalized to 1), more pronounced for the SAN algorithm, as the standard deviation for the Bering-Svalbard Dipole is 0.57 and for Cluster 5 above 1.5, indicating a change in the magnitudes of the pressure anomalies. However, the correlation coefficient remains above 0.7 for all patterns across both algorithms. Alongside with the arguments in section 4.1 and Appendix A, the projected approach is applied to analyse changes in regime occurrence frequencies between the historical and future periods for the Arctic region.*"
L482 Which would mean certain regimes are visited more/less often, instead of lasting longer/shorter. Would be good to comment on this, also in the other section.

We thank you for this suggestions and added after 482: "*This finding indicates that the occurrence of shorter AO$+$ events may be more prevalent regarding the SAN method.*"
Also we would like to refer to L504 comment.

L503 How "small" do changes need to be for supporting this? As there are some changes.

We agree that there are some changes. From Figure R6 we find pattern correlations higher than 0.8 between the future common circulation regime patterns with the ERA5 reference patterns, and we consider that as only small structural change of the patterns, i.e. the positions of the main centers of each pattern are only slightly shifted. We changed L499-501: "To summarize, the calculated circulation regimes of both methods, KME and SAN, exhibit small changes under the influence of global warming in their spatial structure when analysing the Arctic region in the extended boreal summer season from May to October" to "*To summarize, the calculated circulation regimes of both methods, KME and SAN, exhibit small changes under the influence of global warming in their spatial structure when analysing the Arctic region in the extended boreal summer season from May to October but the frequency of occurrence is changing significantly for most of the patterns.*"

L504 Rewrite this sentence, I got lost.

The sentence has been rewritten from " The changes in their occurrence are increased in their robustness by the results analysing the persistence for this pattern." to "*The changes in the frequency of occurrence are in line with the changes in persistence for this pattern, meaning the observed increasing the frequency of occurrence is due to longer lasting events. In contrast to the North Atlantic-Eurasian domain, where we detected a correspondence between occurrence and persistence changes for all regimes, in the Arctic region this correspondence is only found for the AO- regime.*"

L508 See my earlier comment on this. The mechanisms of change are different.

Yes, please refer to Comment 3

L541 Mean change of what? Clarify.

Thank you! We have added "*in mean sea-level pressure*" to clarify.

L544 I find support not the right wording, as they essentially show different things and can help get better insight in the changes in the dynamics.

We have replaced "supports the findings for frequency of occurrence" with "*together with the frequency of occurrence help provide more insight of changes in dynamics*".

L549 See references I suggested earlier on, e.g. looking at the seasonal differences here.

L558 Not really....
We removed the sentence as we present more arguments in the following sentences.
L561 The difficulty with this is that changing one regime affects the assignment of all data sort-of close, and thus the other regimes as well,...

L577 ???
This was a wrong statement, we removed the sentence.
L586 Please add an extra line to make clear this is no longer linked to Q3.
Done.

L632 And not with 4? Or 6, 7,...?
This is why we now do not talk about the optimal cluster number but a suitable cluster number.

Additionally, we made the following changes to clarify and readability:

L289: added *"even".*
L290: removed *The correlation coefficients reach values above 0.85 for all five regimes and the standard deviations of the common simulated circulation regimes are found to be in close proximity to the reference values.*

To avoid misunderstandings we replaced the term of simulated or projected changes in frequency of occurrence or similar terms to detected or future changes. (because we already use simulated or projected approach for the regime determination):
L332: " … is projected to decrease in their frequency of occurrence" into "displays a significant decrease in occurrence frequency"
L355: "simulate" into "*detect*"
L356: deleted "simulate"
L357: "The same applies for the projected the NAO- regimes" into "The same applies for the future change of the NAO- regimes…"
L420: "projected" into "*future*"
L421: "trend" into *"change"*
L483: "trend" into *"change"*
L544: removed "that are projected to"

L337: "predicted by the" into "*when applying*"

L349: “The other observations regarding the storylines and changes in frequency of occurrence cannot be confirmed, that may be due to the small sample size of each storylines, i.e. one or two models” into “*All other regimes do not show any dependence of the changes in occurrence frequency on the storyline. One reason for that might be the small sample size of only one or two models representing each storyline*.”

L416: “pattern” into *“regime”*.

L479 “projected” into *“future”*

L483: removed “also”

L488: removed “under global warming”

L497: rewrote “poleward shift” to “*poleward shifted jet*”

L545: rewrote “trend” to *“tendency”*