

Reviewer Response ‘Boreal autumn to winter North Atlantic atmosphere-ocean coupling in large ensemble climate simulations’

Yvonne Anderson, Amanda C. Maycock, Julianne Schwendike,
Thomas J. Bracegirdle, Simon A. Josey, and Doug M. Smith

October 2026

We thank the Editor for sourcing two detailed reviews of our manuscript. We are grateful to the reviewers for their time evaluating the manuscript and for their constructive suggestions for improvements. We have taken on board the comments and revised the manuscript accordingly. We respond to individual points below. The reviewer comments are in black, and the author responses are in [blue](#).

Reviewer 1

General comments

This paper examines the winter atmosphere-autumn SST relationship in ERA5 and CMIP6 models to assess the representation of atmospheric response to SST over the North Atlantic region. It starts with a MCA analysis between SLP and SST in simultaneous and lagged analysis, finding largely consistent concurrent MCA but not for lagged MCA in CMIP6 against ERA5. This underestimation of lagged response in MCA is then assessed, and seems to be confirmed, in an independent approach of atmospheric circulation analogue on the autumn surface heat flux. This is a comprehensive analysis of the CMIP6 models against observations and provides a reference that can be compared against using other methods. The results are generally interesting. Nevertheless, the complex analysis, with multiple data sets and multiple methods (MCA, EOF, concurrent and lead-lag analysis, and analogue method) makes it a great challenge to follow. I recommend a minor revision before the publication of the paper.

[Thank you to the reviewer for their supportive comments about the scientific merit of our study. We appreciate their suggestions for ways to better clarify the different methodologies used in the analyses and their contribution to the overall conclusions.](#)

Major comments

My major comments concerns with the presentation of the results, instead of the result.

The paper uses a comprehensive analysis strategy that employes multiple methods, but didn't give a guideline of this complex strategy of analysis. For example, the lead-lag MCA analysis has been used

to isolate atmospheric driving of and response to SST in the first half of the paper. Then, it uses the analogue method on surface heat flux to re-examine the feedback. This is my understanding after some long-time contemplation, because the paper didn't lay out this strategy clearly. Similarly, the paper also uses MCA analysis and then compares with the EOFs of single variables to check if the coupled mode explains the dominant variability in each field...

It will be useful to readers to state clearly the strategy of the paper. For example, why using the lead-lag MCA is not sufficient and the analogue method need to be used? I suggest the authors to add a subsection explicitly in 2.3 Method to describe the overall strategy, and the reason why so many different methods have to be used.

Thanks for this feedback on how to improve the clarity of the analysis strategy. We have added a new subsection (2.3.1 "Overview of analysis strategy"), which explains why the three main analysis methods are used. This section highlights why lagged MCA alone cannot distinguish an ocean feedback from atmospheric persistence, which motivates the use of the circulation analogue decomposition.

Also, it will be very helpful for readers, after the application of a method, specify what has been learned and what are the remaining problems, and how this problem can be resolved using another method. This naturally introduces another method, making the paper flow more smoothly. For example, after the lead-lag MCA analysis, what has been learned on the response and feedback, and what is the remaining question. How this remaining question is to be addressed, using another method, such as the analogue method.

We have added more detailed summary paragraphs at the end of sections 3.1, 3.2 and 3.3. Each states what has been learned from that section of the results, what questions remain and how the next stage of the analysis aims to address them.

It is perhaps also useful to highlight that this paper concerns more on the atmospheric response to SST (or the feedback of SST on the atmosphere in models against observations), since the atmospheric driving of SST seems to be a robust feature in models as in observations. It is the feedback part that show diverse results in the models, consistent with GCM simulations (Kushnir et al 2002) and the signal-noise paradox. Accordingly, the discussion on the feedback part should be given higher priority than the driving part, than in the current version of the paper.

Thanks for the suggestion to better highlight the key results. We have reorganised the discussion section accordingly to highlight the weaker model agreement on the lagged SST-atmosphere relationship, adding references to GCM studies as suggested.

Reviewer 2

General comments

This manuscript investigates the coupling between boreal Autumn ocean variability and Winter atmospheric circulation in ERA5 reanalysis and CMIP6 models. They use a variety of techniques including MCA, EOFs and a circulation analogue decomposition. They find that while models generally accurately represent contemporaneous modes of ocean-atmosphere co-variability, they do not show a lagged relationship between Autumn sea surface temperature and the Winter North Atlantic Oscillation (NAO) as strong as that seen in reanalysis. They conclude from the circulation analogue decomposition that the Autumn SST-winter NAO relationship is not the result of SST variability independent of atmospheric-driving. The paper raises questions about the mechanisms by which Autumn SSTs relate to winter circulation.

This paper addresses an important question which fits well within the scope of WCD and is generally well written. I have a few relatively minor comments and recommend publication once these points have been addressed.

We thank the reviewer for their positive comments about the scientific merit of the study and its suitability for publication in WCD.

Minor comments

Statistical significance. It would be useful to have stippling (or similar) showing statistical significance in many of the figures (e.g. figures 1 and 4). This would help to indicate in which regions the coefficients are particularly unusually anomalous and less likely the result of random correlations.

We thank the reviewer for this suggestion and agree that indicating statistical significance helps with interpreting the MCA patterns. Stippling has been added to Figures 1 and 4 in the manuscript to show where the patterns are statistically significant at the 5% level.

The authors show large differences in the MCA coefficients for Autumn SST and winter SLP between ERA5 and models (figure 5) - is there a way to show that this isn't consistent with sampling uncertainty given the relative length of the observational record?

The following text has been added to section 3.11 for clarity:

“Each ensemble member covers the same 1940-2014 period as ERA5 and MCA is applied to each member individually before averaging. The spread across ensemble members therefore represents the sampling distribution of MCA patterns obtained from a 75 year record. Hatching denotes where the ERA5 MCA amplitude exceeds the 97.5th percentile of the distribution of all model ensemble members, and equivalently falls below the 2.5th percentile for stippling. The spatial structure of MCA modes 1-3 of the autumn SST-MSLP relationships are, on average, well captured by the models. ERA5 lies within the ensemble spread at most gridpoints, which means individual members can produce autumn SST MCA patterns that are locally as strong as ERA5.”

We have computed the area averaged MCA1 autumn SST amplitude over the central North Atlantic region to show where individual ensemble members capture the ERA5 amplitude (Fig. R1). This figure has been included in the supplementary information (Fig. S34) and the following text has been added in lines 259-262:

“The area averaged MCA1 autumn SST amplitude over the central North Atlantic region was computed for each ensemble member (Fig. S34). The ERA5 amplitude exceeds every member in 9 of 14 models. Across all models, only 5 ensemble members out of 371 have a lagged MCA1 autumn SST amplitude in the central North Atlantic equal to or greater than that in ERA5. The difference in the autumn SST precursor is therefore unlikely to be explained by sampling uncertainty alone.”

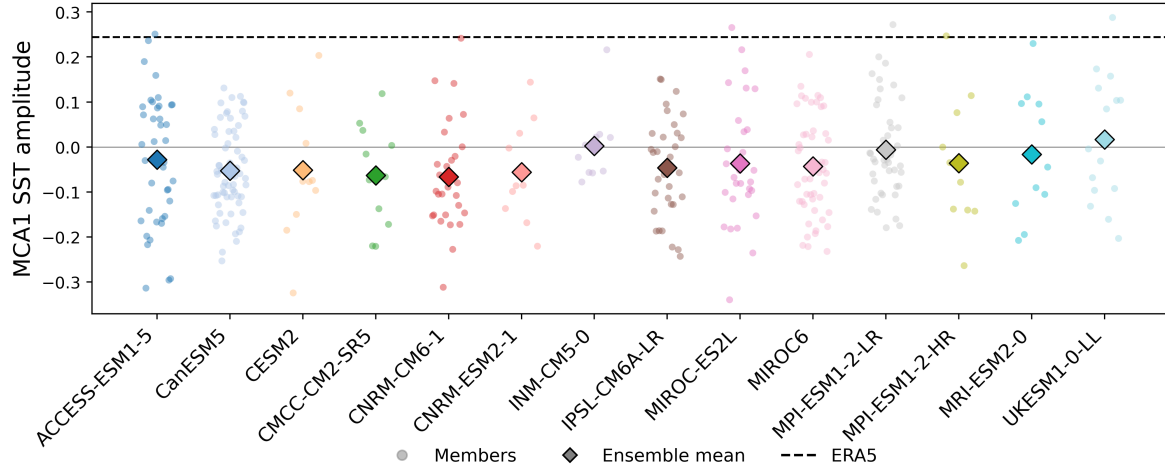


Figure R1: Lagged autumn SST–winter MSLP MCA mode 1 SST pattern averaged over the central North Atlantic (35–45°N, 45–25°W). Circles show individual ensemble members, diamonds show ensemble means and the dashed line shows ERA5.

On the question of the causes of the relationship of Autumn SST and Winter SLP, it would be useful to know to what degree SSTs persist from Autumn to Winter – does an MCA analysis or regression analysis Autumn SST and winter SST show strong co-variability?

We agree that information on the persistence of SSTs is a useful addition to the analysis. Figure R2 shows the December, January and February SST anomalies regressed onto the autumn MCA1 SST expansion coefficients in ERA5 and the multi-model mean. The autumn MCA1 SST pattern persists into winter in ERA5 and the models. ERA5 lies within the 2.5-97.5th percentile range of ensemble member regression values at most gridpoints.

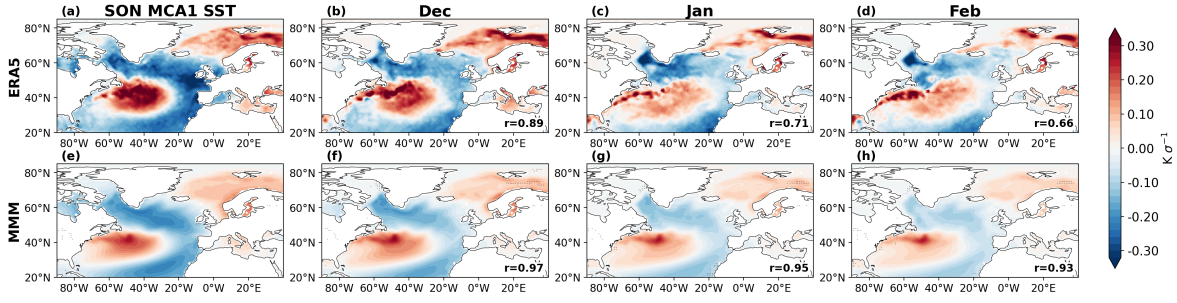


Figure R2: Persistence of the SON MCA1 SST pattern in ERA5 and models. Regression of December, January and February SST anomalies onto the SON MCA1 SST expansion coefficients in ERA5 and the MMM. The spatial correlation with the SON MCA1 SST pattern is shown by the r value in the bottom right corner of each plot. Stippling in (e)-(h) indicates where the ERA5 regression is outside of the 2.5-97.5th percentile range for all members.

Figure R2 has been added to the manuscript (Fig. 7) and the following text has been added in lines 277-285:

“The lagged MCA cannot establish whether the ERA5 relationship reflects a feedback of the ocean onto the atmosphere. One possible explanation for the weaker lagged relationship in the models is that precursor autumn SST anomalies persist less strongly into winter than in ERA5. Figure 7 shows the regression of monthly SST anomalies for December, January and February onto the autumn SST-MSLP MCA1 expansion coefficients in the models and ERA5. We use the autumn MCA1 patterns because these are similar between the models and ERA5 (Fig. 1a and Fig. 2a), and they resemble the lagged autumn SST - winter MSLP MCA1 pattern in ERA5 (Fig. 4a), unlike the equivalent lagged MCA1 patterns in the models (Fig. 5a). The autumn SST pattern persists into winter in ERA5 and the models and the ERA5 regression lies within the 2.5-97.5th percentile range of all ensemble members over most of the North Atlantic. This result suggests that the weaker lagged autumn SST-winter MSLP relationship in the models cannot be attributed to weaker persistence of North Atlantic precursor SST anomalies.

Further reference to this figure has been added in the discussion in lines 393-394 and lines 409-411:

“the persistence of the winter NAO precursor autumn SST anomalies into the winter is also comparable between the models and ERA5 (Fig. 7).”

“As the models reproduce the persistence of these SST anomalies into winter (Fig. 7), any model deficiency in this pathway would have to lie in the atmospheric response to the persisting SST anomalies rather than in the persistence itself”

In the discussion, the authors mention a few potential causes of the Autumn SST – winter SLP relationship including SST anomalies generated in autumn persisting to winter and remote driving via Rossby waves from the tropical Pacific. Firstly, does figure 7e, showing a relationship between autumn circulation-driven THF and weakly positive NAO-like SLP, give some evidence for the former?

We agree that a winter NAO signal associated with autumn THF_{circ} could be consistent with atmospherically forced autumn SST anomalies persisting into winter and contributing to a lagged feedback. However, this cannot be taken as evidence for that mechanism specifically. A mechanism involving teleconnections that affect both autumn and winter atmospheric circulation, such as the intraseasonal teleconnection of ENSO (Ayarzagüena et al., 2018), could in principle produce a similar relationship. We also note the answer to the previous comment showing that the autumn precursor SSTs that resemble MCA1 in ERA5 show similar behaviour in the models. Therefore, we have left these as possibilities in the discussion.

Secondly, could the stratosphere be an additional player in creating a lagged relationship (e.g. Collingwood et al 2024).

We agree that this could be an additional pathway. The stratospheric polar vortex is not known to affect the early winter East Atlantic pattern which is the pattern that mainly drives THF_{circ} . However, a remote driver which impacts the autumn THF_{circ} and also impacts on the stratosphere could produce a winter NAO signal via stratosphere-troposphere coupling. The following text on this potential pathway has been added to the discussion in lines 422-424:

“Another possible pathway for autumn-winter covariability could involve the stratosphere if an autumn teleconnection drives THF_{circ} and also affects the stratospheric polar vortex leading to an NAO signal in winter (e.g. Ineson and Scaife (2009)).”

References

- Ayarzagüena, B., Ineson, S., Dunstone, N. J., Baldwin, M. P., and Scaife, A. A. (2018). Intraseasonal Effects of El Niño–Southern Oscillation on North Atlantic Climate. *Journal of Climate*, 31(21):8861–8873.
- Ineson, S. and Scaife, A. A. (2009). The role of the stratosphere in the European climate response to El Niño. *Nature Geoscience*, 2(1):32–36.