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Dear Prof. Dr. Piotrowska,
dear Reviewers,

Thank you for the opportunity to revise our paper on “North Atlantic Oscillation polarity during the past 3000 years derived from sediments of large lowland lake Schweriner See, NE-Germany” by Adolph et al. Reviewer suggestions were very helpful, and we also appreciate the reviewers’ comments and suggestions.

We completely revised and restructured the manuscript according to your suggestions. The most relevant change made in the manuscript is a restructuring of the Results and Discussion section to Results, Interpretation and Discussion. Please find below a detailed reply to all reviewer comments. The revised versions of the manuscript were uploaded as PDF file with track changes and as PDF file with all changes accepted. Thank you for considering our manuscript for publication.

Sincerely,

Marie-Luise Adolph

Responses to Reviewer 1

General comments:
The manuscript by Adolph et al. provides a reconstruction of North Atlantic Oscillation (NAO) polarity during the past 3,000 years, derived from lake sediment profiles from Schweriner See, located in NE Germany. The authors employ a multi-proxy approach to interpret past climatic signals. The manuscript presents data of good quality, with clear and organized figures. The supplementary data is well-structured and easy to navigate. In general, the manuscript aligns with the scope of the journal.
However, I have several concerns that should be addressed before publication. Firstly, the authors employ an impressive number of methods (over 10), but many of them lack proper descriptions in the results section, and some are not even mentioned (e.g., grain size analysis). The discussion requires revision since, in its current form, it covers various aspects, such as NAO, climatic events, lake level fluctuations, and minerogenic delivery. However, most of these aspects remain speculative at this point, as the discussion rarely relates to the results. I strongly recommend focusing on the obtained results first, and then comparing them with findings from other sites. The lack of a comprehensive discussion of the results creates the impression that many of the analyses conducted were unnecessary, as their usefulness in the current form of the manuscript is unclear.
We restructured the Results and Discussion sections into Results (Lines 229-270), Interpretation (Lines 271-430) and Discussion (Lines 431-574) to make the manuscript more consistent and easier to follow for the reader. Moreover, we restructured the Results section to better address the employed methods.

Specific comments:
The introduction should clearly state the knowledge gap, specific study goals, and hypotheses.
We revised the introduction, restructured it to better address knowledge gaps, study goals and hypothesis.

The term "dominating mode of the NAO" needs a better explanation for clarity.
We replaced the term “dominating mode of the NAO” by “respective mode of the NAO” (L. 106)

Explain the uneven uncertainty of the age-depth model.
The age-depth model was calculated using the r-package “rbacon”. We used the mean and the respective error is based on the 95% confidence interval, in which the probability function is included. We added (Lines 149-141): “In the following, ages are reported as 'rbacon’-derived mean ages and the uncertainty is based on the upper and lower limits of the 95 % confidence interval (Fig. 2).”

Rewrite the results section. Currently, it combines results with their interpretation and references to the literature. In this section, only the authors' results should be described. Additionally, the authors have provided over 10 analyses in the methods, some of which are poorly described or not mentioned, such as grain size analysis.
The entire results section, in particular Lines 248-270, were rewritten to better account for all applied methods. We do not examine individual units anymore but rather focus on each parameter to consider all of them adequately.

Extending the profile to 1000 cm without time control may not provide a broader perspective. If the extension is relevant, it should be mentioned in the methods section and discussed.
We now only show the upper 9 m, for which we have a robust age control.

Address the discrepancy in the age designation (with changed uncertainty sign) in the introduction part of the discussion.
To avoid confusion with the changed uncertainty sign and based on the suggestion later in the review, we removed most CE ages.

Clarify the resolution of distinct analyses and the number of years covered by each sample.
As shown in Fig. 2, the sedimentation rate changes from 2 to 10 mm a^{-1}, which changes also the resolution covered by each analysis. Based on the suggestion, we added the range of years covered by each analysis in the Methods section, e.g. in Line 164: "Discrete samples were taken in a 1 cm resolution ***(equivalent to a 1-6 year temporal resolution)*** *using LL-channels (Nakagawa, 2014)."*

Discuss whether the diatom signal related to long-lasting ice covers could have been captured for a single, extreme winter event.
To address this issue, we added in the methods section that "For diatom analysis, 91 samples with a one-centimetre thickness and 1-2 cm^3 volume were taken in the same sampling resolution (equivalent to a 16-85 year temporal resolution) as the pollen analyses." (Lines 212-213). We further added in the interpretation section "Based on the sample thickness for diatom analysis of one centimetre, which covers 1-6 years depending on the sedimentation rate, it is not possible to distinguish between individual years. However, the regularity in the occurrence of S. chantaicus suggests that single events are likely not responsible but rather long-lasting changes in environmental conditions, which is also supported by long-lasting phases of lower productivity during which S. chantaicus occurs (units C and E, Fig. 4)." (Line 304-308)

Explain the link between inc/coh and milder winter temperatures, as this ratio was previously associated with lake productivity.
In the revised version, we added section "5.1.1 Organic matter as an indicator for winter temperature variability", in which we explain the link between inc/coh, which is indicative for the organic matter content, productivity and milder winter temperatures in detail, e.g. in Lines 299-304: "Such long-lasting ice-covers under colder winter conditions may substantially affect the seasonal heat budget, timing and length of stratification but also the productivity of aquatic ecosystems (e.g. Bonsal et al., 2006) because long-lasting ice covers delay the onset of the growing season and/or reduce water temperatures, which results in a reduced productivity of the lake system. In contrast, during milder winter temperatures the growing season may start earlier and surface water temperatures may already be increased, which prolongs the growing season and results in a higher productivity of the lake system."

Technical corrections:
Add "years" to the title: "...during the past 3 ka years..."
Based on the suggestion from reviewer 2, we changed the title to "North Atlantic Oscillation polarity during the past 3000 years derived from sediments of large lowland lake Schweriner See, NE-Germany".

Use a consistent age unit (CE, cal BP, centuries) for clarity.
In the revised version, we use cal BP as consistent age unit.

Correct the syntax error in lines 34-37.
We corrected the text to "Some areas in Central Europe, such as NE-Germany, have already been affected by lowering lake and groundwater levels (Germer et al., 2010)."

Provide the lengths of cores SAS21-11 and SAS21-12 (line 121).
We added the respective lengths of 13.56 and 15.51 m (Line 117).

Color is also is one of the sedimentological properties (line 126).
We removed sediment colour here.

Correct the sentence in line 237: "…variations in organic matter variations…".
We changed to "variations in organic matter content" (Line 232)

Ensure that depth ranges are consistently provided, with the shallower depth mentioned first.
During the revision of the manuscript, we rewrote this section and do not mention specific depths anymore.

Line 250 is an interpretation, not a result.
This was addressed in the restructuring of the results section.

Use consistent language (British English vs. American English) throughout the manuscript.
BE is used consistently in the revised version of the manuscript.

Add a period at the end of the sentence in line 359.
We added the period at the end of the sentence.

Include information on the location of Dosenmoore (line 402).
We added "ca. 105 km northwest of Schweriner See" and a reference to Fig. 5, where the location of Dosenmoor is shown on a map. (Line 483)

Add a space between "spread" and the citation (line 438).
The space was be added.

It would be good to include map of Europe in Figure 1 for clarity and changing the brackets in the depth scale from () to [] for consistency.
Instead of only adding a map of Europe, we included a conceptual overview of the NAO over Europe and added the location of Schweriner See within (Fig. 1A). Additionally, we changed the brackets as suggested (Fig. 1C).

Ensure consistent terminology in Figure 2 (yellow "remains" vs. "residue").
We changed it to "remains" for consistency.

Label the panels in Figure 3 for clarity (e.g., A and B or upper and lower).
As suggested, A and B was added.

Revise Figure 6 to have consistent numbering for regions (e.g., A, B, and C for Poland, Eastern Central Europe, and Mid Europe). Clarify the difference between "Mid" and "Central."
We used both terms "Mid Europe" and "Central Europe" as these were the terms used in the original publications. To differentiate and clarify the difference we changed "Mid Europe" to "Jura mountains". Based on the suggestion, we changed the numbering of the regions to A, B and C.

Responses to Reviewer 2

The manuscript by Adolph et al. titled 'North Atlantic Oscillation polarity during the past 3 ka derived from lacustrine sediments of large lowland lake Schweriner See, NE Germany' presents a study of a lake sediment core integrating scanning techniques, sedimentological, bulk geochemical, pollen, diatom and leaf wax records. Aim of the study is to reconstruct the environmental factors modifying sediment deposition.

The efforts undertaken are methodologically state of the art and the results provide insights into the regional climate dynamics within the last 3000 years. Therefore, the study can be of interest for a broader geoscience community and would be suitable for publication in Climate of the Past. However, before publication the results/proxy interpretations should be discussed in a more rigorous way, some generalizing statements should be specified or revised and the manuscript would benefit from reorganization.

Main points:
I would prefer to read a more focussed, results-based and mechanistic discussion of the possible factors controlling organic matter accumulation, preservation and degradation in Schweriner See and, consequently, the relevance of the area600-700, LOI550, TOC, TN and inc/coh proxies. In this version of the manuscript area600-700 is defined as productivity indicator in the methods section based on one citation (lines 156-157) and LOI550, TOC, TN and inc/coh are defined as productivity proxies based on their correlation with area600-700 in the results section (lines 256-258). Therefore, the presented proxy interpretations and lenghty paleoclimate implications remain ta degree speculative. In addition, the reconstructed NAO polarity and precipitation records from Schweriner See do not match well (e.g. around 700 or 2500 a BP). Please discuss these discrepancies between both proxies, as both should be interconnected. In general, the manuscript would benefit from a clearer distinction between the methods, results and discussion sections.
We restructured the Results and Discussion sections into Results (Lines 229-270), Interpretation (Lines 271-430) and Discussion (Lines 431-574) to make the manuscript more consistent and easier to follow for the reader and to better explain the involved processes (e.g. organic matter accumulation and preservation).

Moreover, we added a section within "6.3 Driving mechanisms for lake-level variations" to discuss, among other things, the discrepancy between NAO and lake-level variability (Lines 545-564). Please keep in mind that the addressed "precipitation record" is the minerogenic input, which was not addressed solely as precipitation but as shoreline distance record within additional influences of wind speed changes, e.g. in Lines 428-430 "In conclusion, the main drivers for minerogenic input to the coring location of SAS21 at Schweriner See are shoreline distance variations with additional wind speed influences amplifying wave action, particularly under NAO+ conditions."

Specific comments:

Lines 39-40: Continentality is to my knowledge controlled by a place's distance from the ocean and not directly connected with the NAO.
We rewrote these lines to "Recent climate in North Germany has a spatial climatic gradient with increasing continentality from west to east." (Line 57)

In think the introduction can be streamlined and better organized.
We reorganized the introduction in the revised version of the manuscript.

Lines 327-328: This statement is not true. Small lakes do not generally suffer from anthropogenic overprinting. For example, the sediment records from small Lakes Tiefer See, Belau and Woserin located in the Schweriner See region allowed to reconstruct changes in NAO polarity, humidity and wind speed.
We removed this statement.

Is the construction work for the Paulsdamm AD 1848 visible in the investigated sediment core? This could be a nice time marker.
Generally, the decade around 1850 marks a distinct shift in the sedimentation from calcareous to organogenic sediment in Schweriner See, which was previously shown in Adolph et al. (2022). This distinct change was linked to an increase in population density leading to increases in sewage and, consequently, productivity. This distinct shift was observed in short sediment cores from three different locations and also in the record presented in this study. This is repeatedly noted in the manuscript e.g. "After $105^{+95}/_{-75}$ cal BP, the anthropogenic impact on Schweriner See increased significantly, resulting in in-lake productivity mainly driven by nutrient supply (eutrophication) masking the hydroclimatic signal." (Lines 589-591). This distinct increase in productivity likely masked the signal of the Paulsdamm construction.

The lake sediment record investigated in Olsen et al. (2012) is located in Greenland which is not mentioned in the list.
Greenland was added to the list in the revised version of the manuscript and in Fig. 5.

Since ice cover duration is interpreted to play an important role for productivity changes in Lake Schwerin, it would be interesting to read a sentence about varying ice cover durations during the instrumental period.
Unfortunately, we do not have any data about the ice cover duration during the instrumental period. However, we would likely not see any interplays between ice cover duration and productivity changes because since 1850 CE productivity is not driven by winter temperature changes but by nutrient availability, which masks the temperature signal. We added the following sentence: "After $105^{+95}/_{-75}$ cal BP the temperature signal is masked by eutrophication dominating the in-lake productivity (Adolph et al., 2023), which is why it is not possible to link the reconstruction to monitoring data (e.g. ice cover duration)." (Lines 474-476)

Lake level reconstruction: Please discuss the role of the Stör river draining Schweriner See for the presented lake level reconstruction. Is the river too small to level out lake level changes?
We added the following part to discuss the Stör river "Previously the second outflow, the Stör waterway, likely had no significant influence on the lake-level because, for example, around 1830 CE, the river was so shallow that it was difficult to navigate the Stör even with boats with shallow drafts (Ruchhöft, 2017). Only the expansion of the Stör waterway in the mid-19^{th} century resulted in a lower lake level afterwards (Fellner, 2007; Umweltministerium Mecklenburg-Vorpommern, 2003), which resulted in the division into the two lake basins we see today (Fig. 1)." (Lines 515-519)

Lines 403-405. Different moisture sources do not influence the amount of precipitation.
During the restructuring of the manuscript, we removed those lines.

Lines 429-431. This sentence connects a positive NAO polarity with a coinciding period of dryness in Europe. This contradicts with the statement in lines 64-65, associating a positive NAO with more humid conditions.
We rewrote this to "A shift to positive NAO conditions from $2110^{+160}/_{-130}$-$830^{+100}/_{-90}$ cal BP with a gradual increase in winter temperature until $1720^{+70}/_{-70}$ cal BP coincides with the Roman Warm Period (RWP, c. 2150-1550 cal BP), which was a period of general warmth in Europe (Lamb, 2013)." (Lines 458-460)

Please provide a definition on how you distinguish NAO+ and NAO- time slices based on the Schweriner See data.
We dedicated section "5.1.3 NAO variability" (Lines 348-370) to this issue.

Detailed comments:

Line 52: Delete 's' in 'circulations'.
We deleted this in the revised version.

Lines 244-245: Shortly mention why 897.5 cm core depth is the lower limit.
We added "For this study, only the upper 897.5 cm were investigated in detail as this depth marks the lowermost ^{14}C age and we refrained from extrapolating the age-depth model." (Lines 141-143)

Lines 372-375: Does a distance of 120 km substantially change the degree of continentality and evaporative enrichment?
During the reorganization, we discussed this issue in detail in lines 553-564: "Such influences of evaporative lake water enrichment have been observed for several smaller lakes in north-eastern Germany (Aichner et al., 2022). However, these study sites are located ca. 120 km southeast of Schweriner See in the more continental climate zone, whereas Schweriner See is located in the transition zone between maritime and continental climate. These areas differ by their mean annual water balance, which is negative in northeast Germany but slightly positive at Schweriner See (Adolph, 2024) suggesting an increased evaporative lake water enrichment in lakes east of Schweriner See. Moreover, lake water evaporation in these lakes shows spatially varying amplitudes and seems to depend on the lake's morphological parameters and hydrological features (Aichner et al., 2022). Additionally, lakes similar to Schweriner See, i.e. deep lakes with high water residence times and absence of river connections, show low evaporative lake water enrichment (Aichner et al., 2022). Because δ^2H_{C25} mostly correlates to winter temperature changes at Schweriner See (Fig. 5), we suggest that the δ^2H_{C25} predominantly dependents on moisture source changes in the North Atlantic region potentially explaining differences in the NAO and lake-level reconstructions. Still, an additional influence of evaporative lake water enrichment cannot be completely excluded."

Lines 376-386: This part can be shortened, as a detailed description of the NAO is already given in the introduction.
During the revision, we shortened this part.

Title: Change '3 ka' to '3000 years' in the title, as ka is not used within the text. Delete 'lacustrine' as lake is mentioned too.
During the revision, we changed the title to "North Atlantic Oscillation polarity during the past 3000 years derived from sediments of large lowland lake Schweriner See, NE-Germany"

Fig.1. Except for the coring location is Fig. 1b already included in Fig. 1a. Add the coring location to Fig 1a and delete Fig. 1b?
We would like to show the bathymetry again separately to highlight the distinct morphometry. In particular, the widespread shallow water area is essential for the discussion of the shoreline distance in section 5.2 and 6.2.

Fig. 6. Add 'Grand' to 'Solar Minima'.
During the revision, 'Grand' was added to the figure.