Author's response to Reviewer 1
#Reviewers comments in blue, our responses in black

The authors performed a comprehensive update of the manuscript to address the reviewers' remarks. Overall the quality of the presentation has improved, however I have a few remaining concerns that the authors should consider.

Response: Thank you very much. We carefully considered each of your comments and suggestions, and we would like to respond to them in the following content.

The main issue is that the discussion of the mechanisms, especially in the context of teleconnections, remains poor. Unfortunately, the tracked changed versions does not clearly show changes/additions, as text is generally blue and occasionally red.

Response: We would first like to clarify that, in the tracked manuscript submitted, both blue and red texts indicated changes made by the authors: red text represented newly added material, while blue text mainly indicated deletions or replacements generated by the track-changes display.

We agree that the mechanism discussion, particularly for the teleconnection-related summer response in Cluster 2, was not sufficiently clear in the previous version. In the revised manuscript, we have substantially reorganized Section 3.3 to present the mechanism in a more explicit and physically coherent way.

Specifically, we now first clarify why the strong positive AMV phase can favor a stronger IPO-related atmospheric response. We added discussion, supported by previous studies, that North Atlantic SST anomalies can influence tropical Pacific variability through changes in the Walker circulation and Pacific trade winds, and that ENSO-related teleconnections to the North Atlantic-European sector are sensitive to the SST background state and convection. This provides a physical basis for interpreting the strong positive AMV phase as a background state that enhances the downstream transmission of IPO-related atmospheric variability.

We also revised the part related to teleconnection pathway in Section 3.3 to make the logical sequence of processes clearer. The revised text now explicitly explains the causal linkage among: (1) the strong positive AMV phase, (2) the enhanced IPO-regressed geopotential-height response over the North Pacific, (3) stronger downstream wave activity flux from the Pacific toward North America and the North Atlantic, (4) the associated tropical Atlantic response, and (5) the Euro-Atlantic circulation and cloud anomalies over the northern North Sea.

Finally, we strengthened the connection between the remote teleconnection and the MHW response in the northern North Sea. The revised Section 3.3 now explains that the large-scale circulation anomalies are associated with reduced cloud cover over

Cluster 2, which favors enhanced downward shortwave radiation and a positive surface heat-flux contribution. This atmospheric forcing acts on a shallow and strongly stratified summer mixed layer, allowing heat to be retained near the surface and favoring more frequent and persistent MHWs. We also clarified why this mechanism mainly affects MHW frequency and duration rather than mean intensity.

Overall, the revised Section 3.3 has been rewritten to move from a descriptive correlation-based discussion toward a clearer mechanism explanation linking AMV-modulated IPO teleconnections, Atlantic-sector atmospheric responses, local forcing, and the upper-ocean conditions controlling summer MHW development in the northern North Sea.

L456-543: "*The summer MHWCI variability in Cluster 2 exhibits a distinct dependence on the background state of the AMV. As shown in Fig. 2d, the Cluster 2 MHWCI remains relatively weak during the negative AMV phase but is substantially enhanced during the positive AMV phase before 2013. During this strong positive AMV period, the summer MHWCI is strongly correlated with the IPO index. However, this relationship weakens after 2013, when the correlation with Pacific indices becomes statistically insignificant. These results suggest that the Pacific influence on summer MHW variability in the northern North Sea is not stationary but is modulated by the background state of the North Atlantic.*

To examine this phase dependence, we regressed atmospheric and oceanic variables onto the IPO index during three periods: the negative AMV phase, the strong positive AMV phase before 2013, and the post-2013 positive AMV period. The large-scale atmospheric circulation and horizontal WAF are shown in Fig. 9, while the corresponding wind stress, SST, precipitation, and cloud-cover anomalies are shown in Fig. 10. This comparison allows us to assess whether the IPO-related signal is transmitted from the Pacific to the North Atlantic-European sector and whether it produces a local response over the northern North Sea.

During the strong positive AMV phase, the warm North Atlantic background may have provided favorable large-scale conditions for the development and downstream transmission of IPO-related atmospheric anomalies. Previous studies have shown that North Atlantic SST anomalies can influence tropical Pacific variability by modifying the Walker circulation and Pacific trade winds, thereby affecting Pacific-related variability on multidecadal timescales (Levine et al., 2017; McGregor et al., 2014). In addition, ENSO-related teleconnections to the North Atlantic-European sector are known to be sensitive to the SST background state and upper-level flow, which regulate Rossby-wave excitation and propagation pathways (Fernández-Castillo et al., 2025). Consistent with this background-state modulation, the IPO-related atmospheric response is well developed over the North Pacific during the strong positive AMV phase. The regression pattern of 500-hPa geopotential height exhibits a clear dipole-like structure between the subpolar and subtropical North Pacific. This circulation pattern *is accompanied by enhanced WAF extending eastward from the Pacific sector toward North America and the North Atlantic (Fig. 9a), indicating that IPO-related stationary wave activity is more effectively transmitted downstream under the strong positive AMV background. The tropical Atlantic and Caribbean region also forms part of this broader Pacific-Atlantic teleconnection pattern. During the strong positive AMV phase, northeasterly wind anomalies over the Caribbean Sea are accompanied by reduced precipitation and negative SST anomalies (Fig. 10a-b), suggesting a coherent tropical Atlantic response associated with the downstream atmospheric adjustment. In contrast, the downstream WAF propagation and the convection anomalies are much weaker during the negative AMV phase and after 2013, suggesting that the AMV background modulates the efficiency with which IPO-related atmospheric variability is transmitted from the Pacific into the Atlantic sector.*

This large-scale circulation response is accompanied by enhanced geopotential over the northern North Sea, where the regression patterns show reduced cloud cover within Cluster 2 (black box in Fig. 10c). Reduced cloud cover favors increased downward shortwave radiation at the sea surface and therefore enhances the surface radiative contribution to the upper-ocean heat budget. Consistently, the summer heat-budget analysis shows a positive net surface heat-flux contribution over Cluster 2 (Fig. 6), indicating that atmospheric surface forcing provides an important pathway linking the large-scale circulation response to regional MHW.

The heat-budget analysis further supports this interpretation. In contrast to the winter mechanism in Cluster 1, where geostrophic heat advection associated with enhanced Atlantic inflow provides the dominant warming contribution, the summer temperature tendency in Cluster 2 is mainly associated with surface heat flux and the RES term (Fig. 8). The contributions from geostrophic and Ekman heat advection are comparatively weak. This indicates that the summer MHW response in the northern North Sea is primarily mediated by atmospheric surface forcing rather than by horizontal oceanic heat transport.

The regional upper-ocean structure further determines how this atmospheric forcing is converted into MHW characteristics. During summer, the northern North Sea is characterized by a shallow MLD and strong stratification (Fig. S4b). During enhanced MHWCI summers, the mixed layer becomes shallower over much of Cluster 2 (Fig. 7f), reducing the effective heat capacity of the surface layer. Fig 7g also shows predominantly positive Ri anomalies over the same region, indicating enhanced stratification stability and a reduced susceptibility to shear-driven instabilities. The spatial co-location of MLD shoaling and increased Ri suggests that buoyancy-driven stratification strengthens sufficiently to offset any increase in velocity shear, resulting in a more stably stratified upper ocean during these summers. Together, these changes imply that radiative and surface heat flux anomalies are confined to a thin surface layer, allowing relatively short-lived atmospheric forcing anomalies to produce a pronounced near-surface thermal response. In addition to surface forcing, the regression patterns *indicate a dynamical response in the regional circulation. The reduced Atlantic flow leads to weakened surface winds over the northern North Sea. These wind anomalies are accompanied by negative MOC anomalies (Fig. 7h), indicating an anomalous anticlockwise overturning circulation with enhanced upwelling over the northern North Sea.*

This mechanism is consistent with the observed changes in MHW characteristics. Enhanced summer MHWCI in Cluster 2 is mainly associated with increased MHW frequency and duration, whereas mean intensity slightly decreases. The teleconnection-related radiative anomaly provides a relatively persistent but moderate surface heating tendency. However, the northern North Sea remains dynamically active in summer, and local circulation, vertical exchange, and residual processes can limit the development of strong peak warming. Therefore, the remote atmospheric forcing preferentially increases the persistence and occurrence of MHWs rather than their mean intensity (Fig. 3d-f).”

Referring to works on medical sciences to justify your K-means methods seems odd. I suggest to reference works who followed a similar method in oceanography or climate sciences, as I remain unconvinced of this approach (which to me is mostly equal to consider MHWs in JJA or DJF) in terms of physical interpretation (some statistical considerations are provided in the appendix). I would like to see some comparison of the DJF and JJA average MHW conditions, to understand how they agree with the clusters. And it would be good to include some confidence measure, e.g. based on bootstrapping or subsampling of different periods to assess the relevance of the clusters used.

Response: We thank the reviewer for this important and helpful comment. Firstly, we agree that the previous references from medical sciences were not sufficient for justifying an oceanographic and climate application of the correlation-based K-means method. We have therefore removed these references and revised the methodological justification. In the revised manuscript, we now refer to studies from climate and ocean sciences where clustering or correlation-distance-based clustering has been used to group locations or fields according to the similarity of their temporal variability patterns rather than their absolute magnitudes. This better supports the present use of a correlation-based K-means method for identifying coherent MHWCI variability regimes in the North Sea. The manuscript has been updated accordingly.

L168-L176: “*Distinct regional patterns of MHWCI variability in the North Sea were identified using a correlation-based K-means clustering approach (Jain, 2010; Lloyd, 1982). Clustering methods have been used in climate research to identify spatially coherent regions and recurrent climate or circulation regimes (Jacobeit, 2010; Plaut & Simonnet, 2001). Unlike conventional K-means clustering, which minimizes Euclidean distance and is sensitive to absolute feature magnitude, the correlation-based version* *emphasizes similarity in the shape of normalized feature vectors. Similar correlation-distance-based clustering approaches have been used to classify precipitation variability regimes, identify climatically meaningful oceanic regions from subsurface temperature data, and characterize regional SST variability patterns (Radin & Nieves, 2024; Radin et al., 2024; Santos et al., 2019).”*

Secondly, we further clarified the physical interpretation of the clustering result. Our main point is not that the clustering simply reproduces the DJF/JJA contrast, but that the North Sea MHW variability exhibits a robust north-south regional contrast that can be identified from different perspectives.

We further compared the clustering results with seasonal EOF analyses of winter and summer MHW variability. The EOF results show that winter and summer MHW variability have distinct spatial expressions, with winter variability more strongly associated with the central-southern North Sea and summer variability more pronounced in the northern North Sea (see Figure R1 below). Taken together, the seasonal-pattern clustering, the characteristic-based clustering, and the seasonal EOF analysis consistently suggest that MHWs in the southern and northern North Sea differ in two related aspects: their dominant seasonal expression and their event characteristics. Therefore, the clusters can be interpreted as statistically defined and physically meaningful distinct regimes of North Sea MHW variability.

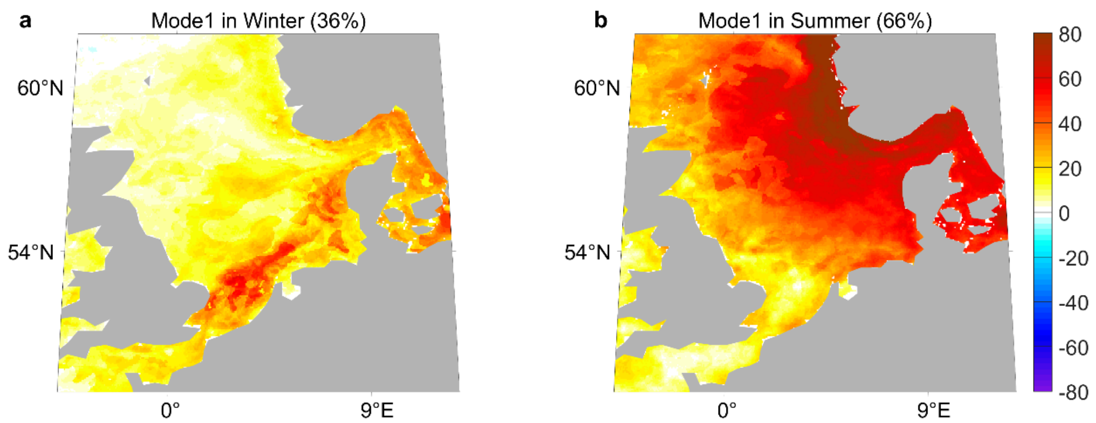

Figure R1. Leading modes of North Sea MHWs variations and associated climate indices. (a) First empirical orthogonal function (EOF) mode of MHWCI in winter from 1982 to 2021. (b) Same as (a), but for summer seasons.

Moreover, in the original Appendix A, we used the elbow method and silhouette coefficient to justify the choice of K and evaluate the statistical separation of the clusters. However, we agree that these diagnostics do not directly quantify the sensitivity of the spatial partition to the selected analysis period. We therefore added a temporal subsampling test as an additional confidence measure.

Specifically, we repeated the correlation-based K-means clustering using moving 30-year windows over the 1982-2021 period. This produced 11 subsampling experiments, covering 1982-2011, 1983-2012, ..., and 1992-2021. For each window, the four-season MHWCI variability vectors were recalculated, and the K-means clustering was repeated with K = 2. Because K-means labels can be permuted between different runs, the cluster labels from each subsampling experiment were matched to the full-period reference clustering according to maximum spatial overlap. The membership confidence at each grid point was then defined as the fraction of subsampling experiments in which the grid point was assigned to the same cluster as in the full-period reference clustering.

The resulting confidence map (Fig. R2) shows that the clustering is robust over most of the North Sea. The mean membership confidence is 0.933, and the median confidence is 1.000. Moreover, 89.1% of the grid points have confidence values greater than or equal to 0.80, and 84.5% have confidence values greater than or equal to 0.90. Lower confidence values mainly occur near the transition zone between the two clusters and in some coastal or marginal regions. This indicates that the broad central-southern versus northern partition is stable across different temporal subsets, while the exact boundary between the two clusters should be interpreted with caution.

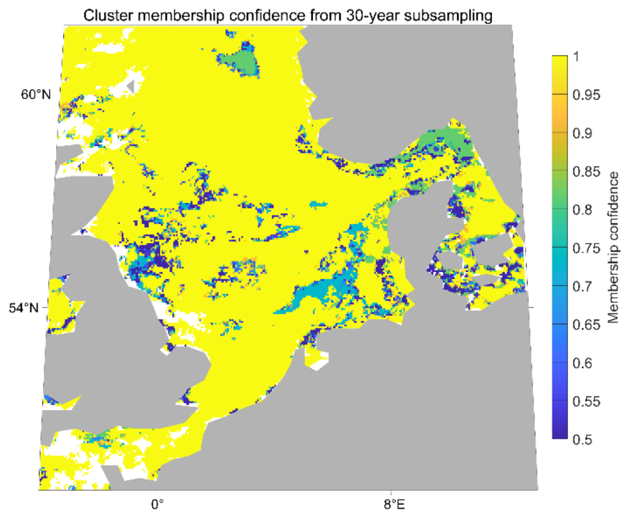

Figure R2. Robustness of the K-means clustering based on temporal subsampling.

We have added this subsampling-based confidence assessment together with Figure R2 (named as Figure A2 in the revised manuscript) to Appendix A and revised the text accordingly.

L689-L696: "*A temporal subsampling test was further conducted to assess the robustness of the clustering. The correlation-based K-means clustering was repeated using moving 30-year windows over 1982-2021, and cluster labels were matched to the full-period reference result according to maximum spatial overlap. The membership confidence was defined as the fraction of subsampling experiments in which each grid point remained in the same cluster as in the reference result. The mean and median* *confidence values are 0.933 and 1.000, respectively, with 89.1% of grid points showing confidence ⩾ 0.80 and 84.5% showing confidence ⩾ 0.90. Lower confidence is mainly confined to the transition zone and coastal or marginal regions, suggesting that the broad north-south partition is robust while the exact boundary should be interpreted cautiously (Figure A2).”*

It is important to distinguish between what the data you used (e.g., ERA5 monthly) and what is available (e.g., ERA5 hourly), as the reader might be misled by some statements in the Methods section.

Response: Thank you for pointing this out. We agree that the previous wording could be misleading because it did not clearly distinguish between the temporal resolution of the ERA5 product itself and the temporal resolution actually used in this study.

In this work, we used monthly-mean ERA5 fields, not hourly ERA5 data. ERA5 is available at higher temporal resolution, but monthly-mean data were selected here to ensure consistency with the monthly MHWCI time series, seasonal climate indices, ORAS5 monthly ocean reanalysis fields, and the seasonal-to-interannual focus of the analysis. The Methods section has been revised accordingly to specify that the ERA5 fields used here are monthly means.

L136-L137: “*Atmospheric conditions were characterized using the monthly ERA5 reanalysis dataset (Hersbach et al., 2020) produced by the European Centre for Medium-Range Weather Forecasts (ECMWF).”*

My suggestion was to revise the order of contents in the Results section "I would suggest to first analyse non-MHW variables and understand how they change over time and due to teleconnections, and then focus on the influence of these indices on MHWs." I don't think this was done, as 3.1 is still about MHWs. Please explain the apparent contradiction with your response.

Response: Thank you for pointing this out. Our previous response did not clearly explain why Section 3.1 still starts with MHW variability, which may have led to this confusion.

Section 3.1 was retained at the beginning of the Results section because it serves as a necessary diagnostic step rather than a mechanism analysis. Its purpose is to identify the regions, seasons, and climate indices most relevant to MHW variability in the North Sea. Specifically, the clustering analysis first shows that winter MHWCI variability is dominant in the central-southern North Sea, whereas summer MHWCI variability is dominant in the northern North Sea. The following correlation analysis further identifies the climate modes most closely associated with these regional and seasonal MHW variations: the EAP for winter MHWs in Cluster 1 and the IPO, modulated by AMV, for summer MHWs in Cluster 2. These results provide the basis for selecting the teleconnection patterns examined in the following mechanism sections. However, we recognize that this organization was not explained clearly enough, especially because Section 3.1 still begins with MHW variability. We have therefore added clarifying statements at the beginning of the Results section and in the transitions to Sections 3.2 and 3.3 to explicitly distinguish the diagnostic role of Section 3.1 from the mechanism analyses based on non-MHW atmospheric and oceanic variables. The following sentences have been added to the beginning of Section 3.1 to provide a logical interpretation:

L263-L265: "*To link regional MHW variability with its large-scale drivers, we first identify the dominant spatial-seasonal patterns of MHWCI and their associated climate indices, and then examine the corresponding atmospheric and oceanic anomalies.* ".

We also clarify that, in the revised manuscript, Sections 3.2 and 3.3 were organized to first analyze the general atmospheric and oceanic variables, and then to discuss their impacts on MHWs. We interpret these "non-MHW variables" as the background physical variables associated with teleconnections, such as geopotential height, wave activity flux, wind stress, surface heat flux, cloud cover, precipitation, mixed layer depth, stratification, ocean circulation, and heat advection. In Section 3.2, we first examined the evolution of geopotential height, wave activity flux, wind stress, surface heat flux, ocean circulation, stratification, and heat budget terms associated with the winter EAP-related circulation anomalies, and then discussed how these conditions favor enhanced winter MHW frequency, intensity, and duration in the central-southern North Sea. Similarly, in Section 3.3, we first analyzed the IPO-related atmospheric circulation, Rossby wave activity, cloud cover, shortwave radiation, upper-ocean stratification, and circulation anomalies under different AMV phases, and then explained how these background changes contribute to more frequent and persistent, but less intense, summer MHWs in the northern North Sea. The following descriptions have been added to Sections 3.2 and 3.3 for clarification:

L343-L346: section 3.2: "*The winter EAP-related pathway in Cluster 1 is examined through the evolution of large-scale atmospheric circulation, surface forcing, regional circulation, stratification, and heat transport. Composite anomalies are calculated for winters when the standardized cluster-mean MHWCI exceeds +1 standard deviation (black line in Fig. 2c), providing the background physical conditions associated with enhanced winter MHWCI.*"

L466-L472: section 3.3: "*The summer MHWCI variability in Cluster 2 exhibits a distinct dependence on the background state of the AMV. As shown in Fig. 2d, the Cluster 2 MHWCI remains relatively weak during the negative AMV phase but is substantially enhanced during the positive AMV phase before 2013. During this strong positive AMV period, the summer MHWCI is strongly correlated with the IPO index.*

However, this relationship weakens after 2013, when the correlation with Pacific indices becomes statistically insignificant. These results suggest that the Pacific influence on summer MHW variability in the northern North Sea is not stationary but is modulated by the background state of the North Atlantic."

The usefulness of very limited validation with "Ferrybox" data (whose uncertainty is not explained) is debatable. I would suggest to add more comprehensive analysis (e.g. scatter plots and other dispersion analysis for longer periods) and to better explain how data are collocated.

Response: We thank the reviewer for this helpful suggestion. We agree that the previous FerryBox validation was too limited and that the collocation procedure and uncertainty sources required clearer explanation. In the revised manuscript, we have expanded the SST validation using 17 FerryBox routes covering 2013-2020. Because FerryBox observations are high-frequency along-track measurements, whereas OSTIA provides daily gridded SST fields, we performed the comparison at the daily and grid-cell scale. Specifically, each FerryBox measurement was assigned to the nearest OSTIA grid cell and corresponding date. Multiple FerryBox records within the same grid cell and same day were averaged before comparison.

We added a new supplementary figure showing the daily collocated SST time series between OSTIA and FerryBox observations. The comparison shows very close agreement, with 1428 matched days, a correlation coefficient close to 1.0, a mean bias of -0.33 °C, an RMSE of 0.52 °C, and an MAE of 0.39 °C. These results support the ability of OSTIA to represent daily SST variability along the FerryBox ship tracks. We have also clarified that this comparison should be interpreted as an independent along-track consistency check rather than a full spatial validation of MHW metrics, because FerryBox observations are limited to commercial ship routes.

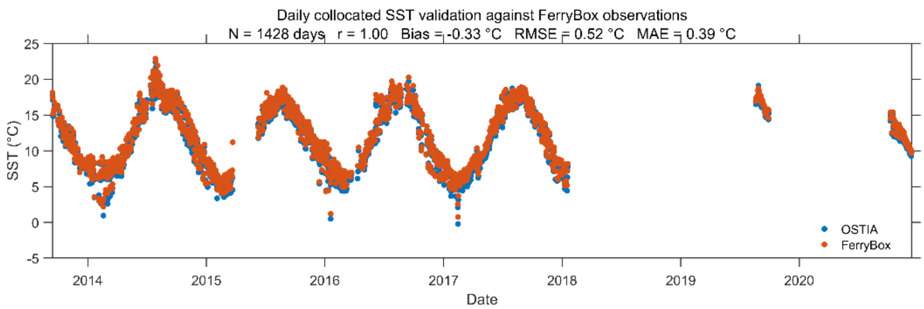

Figure. S1. Validation of OSTIA SST against FerryBox observations. Daily collocated OSTIA SST and FerryBox temperature from 17 routes during 2013-2020 are shown. FerryBox measurements were matched to the nearest OSTIA grid cell and corresponding day before daily averaging. The statistics indicate the number of matched days, Pearson correlation coefficient, mean bias, RMSE, and MAE.

The code on zenodo reports much text written in Chinese characters, which may not be easy to understand to all readers. Consider translating it. Other metadata in the zenodo page needs to be aligned with the submitted paper.

Response: We thank the reviewer for pointing this out. We have revised the code archive deposited on Zenodo accordingly. All Chinese comments and text in the code files have been removed or translated into English to improve readability for all users. In addition, we have checked and updated the metadata on the Zenodo page to ensure consistency with the submitted manuscript. The titles of the individual code files have also been revised so that they correspond directly to the relevant analyses and figures described in the paper.

Comments by line

138 while this can be considered a valid approach, previous works documenting the effects of detrending should be referenced

Response: Thank you for this suggestion. We agree that the rationale for detrending should be made clearer. In the original manuscript, Liu et al. (2022) was cited because this previous MHW study documented the influence of detrending when examining climate-mode-related MHW variability. However, we agree that this point was not sufficiently explicit in the text. We have revised the sentence to clarify that detrending was applied to better isolate climate-mode-related variability from the long-term warming background, following previous MHW studies.

L118-L119: "*The SST time series was detrended before MHW detection to reduce the influence of background warming on MHW detection and characteristics and to better isolate climate variability (Liu et al., 2022)*."

Fig. 1 title: not sure if updated, but you are showing bathymetry (i.e., values below sea level) and not topography (i.e. values above sea level).

Response: We thank the reviewer for pointing this out. We have revised the figure title and caption accordingly by replacing "topography" with "bathymetry".

617 What would RES be?

Response: Thank you for the comment. RES was defined in Section 2.4 as the residual term of the mixed-layer heat budget. Therefore, in this part of the Results section, we intended to use the abbreviation directly. To avoid confusion, we have revised the sentence by removing the repeated definition "residual (RES)" and using "RES" consistently after its first definition in the Methods section.

724 why repeating this here?

Response: Thank you for pointing this out. We understand that the original sentence repeated the detrending procedure already described in the Methods section. Our intention in the Discussion was not to restate the method, but to emphasize the implication of the detrended results: the increase in MHW frequency and duration, together with the slight decrease in intensity in Cluster 2, persists after removing the long-term warming trend. This suggests that the observed pattern is not simply a consequence of background warming, but is likely related to large-scale atmospheric circulation changes and regional oceanic processes. We have revised the sentence to avoid repetition and to focus on this interpretation.

L594-L605: "*The detrended results show that Cluster 2 exhibits increased MHW frequency and duration, accompanied by a slight decrease in intensity during positive MHWCI periods. This pattern suggests that the summer response in the northern North Sea cannot be attributed solely to the long-term warming trend. This result is consistent with basin-wide observations from 1993 to 2022, which show a declining trend of MHW intensity but increasing frequency and duration (Chen & Staneva, 2024). Such a change is attributed to large-scale atmospheric circulation changes and regional oceanic processes rather than global warming. The reduction in intensity has been proposed to be related to the weakening of the North Atlantic Jet Stream and more frequent atmospheric blocking events (Woollings et al., 2018), which promote stagnant atmospheric conditions and persistent but less intense warm anomalies over the North Sea, while freshwater-salt exchange, stratification changes, and Baltic Sea inflow also modulate regional SST responses (Mathis & Pohlmann, 2014). As an additional possible mechanism, the interannual-decadal variability linked to the AMV and Pacific teleconnections could modulate the summer North Atlantic atmospheric pattern, which then changes MHW intensity in the northern North Sea*."

754 rather than "incorporate", I think ideally these should be "realistically simulated"

Response: Thank you for this helpful suggestion. We agree that "realistically simulated" is more appropriate than "incorporated" here, because the predictive value of these relationships depends on whether forecast systems can represent the underlying spatially and seasonally varying physical processes, rather than simply including empirical relationships. We have revised the sentence accordingly.

L622-L626: "*These contrasts highlight that MHW predictability in shelf seas depends on the timing, location, and combined effects of multiple climate drivers rather than their individual strengths alone. Realistic simulation of these spatially and seasonally varying relationships in forecast systems would improve the ability to predict when and where MHWs are most likely to occur*."

Author's response to Reviewer 2
#Reviewers comments in blue, our responses in black

Review of the revised version of "Climate Modes Synergistically Influence Marine Heatwaves in the North Sea" by Lin et al. The authors have revised the manuscript extensively in response to the reviewer's comments, which has strengthened it. I have some additional comments below; in particular, it is difficult in a few places to relate statements in the text to what is shown in the figures.

Response: Thank you very much. We carefully considered each of your comments and suggestions, and we would like to respond to them in the following content.

Line 374 – it isn't clear to me what the intensification of cyclonic wind anomalies over the subpolar Arctic is referring to in Fig 5b. If anything, wind stress looks to have reduced between October and November.

Response: Thank you for pointing this out. The original wording was inaccurate. The cyclonic wind-stress anomaly referred to in this sentence is not located over the subpolar Arctic region, but mainly over the mid-latitude North Atlantic, approximately between 20°N and 50°N. We have therefore revised the sentence to avoid this misleading description.

L376-L377: "*In November, the region of SST cooling expands northward and eastward, following the intensification of cyclonic wind anomalies over the mid-latitude North Atlantic*."

Line 390 – it is stated that shortwave and longwave fluxes are partially compensating each other, but both are negative.

Response: Thank you for pointing this out. The original statement was inaccurate. We have revised the sentence to avoid this unsupported interpretation and now only describe their relative magnitudes.

L391-L392: "*Among the individual components, the sensible heat flux exhibits the largest negative anomalies, while the latent heat flux, shortwave radiation, and longwave radiation anomalies are comparatively weaker in magnitude*."

Line 480 – sentence is incomplete (it looks like there should be some text after 'a broader').

Response: We thank the reviewer for noticing this incomplete sentence. This was a writing error in the previous version. In the revised manuscript, this section has been substantially reorganized, and the incomplete sentence has been removed. We have also carefully checked the surrounding text to ensure that the revised paragraph is complete and clear.

Line 485/486 – southeasterly winds over the northwestern North Sea aren't shown in figure 10a. There is also a similar statement in line 507.

Response: Thank you for pointing this out. The southeasterly wind anomalies over the northwestern North Sea are not clearly shown in Fig. 10a, because this part of the wind field does not pass the significance test. The original statement therefore over-interpreted a non-significant feature. To avoid this unsupported interpretation, we have deleted this sentence and the similar statement in Line 507 from the revised manuscript.

Line 520 – it is difficult to see the reduction in precipitation referred to in this line.

Response: Thank you for this comment. The original wording was too general and did not clearly indicate the region where the precipitation signal weakens. What we intended to describe is that, compared with Fig. 10b, the precipitation anomalies in Fig. 10e become weaker over the tropical central Atlantic and the Caribbean Sea, with the reduction being particularly evident over the tropical central Atlantic. We have revised the sentence to make this regional comparison clearer.

L492-L496: "*The tropical Atlantic and Caribbean region also forms part of this broader Pacific-Atlantic teleconnection pattern. During the strong positive AMV phase, northeasterly wind anomalies over the Caribbean Sea are accompanied by reduced precipitation and negative SST anomalies (Fig. 10a-b), suggesting a coherent tropical Atlantic response associated with the downstream atmospheric adjustment.*"

Other minor comments:

Fig 4 and 5 caption, it says that these are based on winters with positive values in the cluster-specific time series, but lines 339-341 suggest it is winters with normalised MHWCI > 1 – please can this be clarified in the captions.

Response: Thank you for pointing out this inconsistency. The composites are based on winters when the standardized cluster-mean MHWCI exceeds +1 standard deviation, rather than all winters with positive values. We have revised the captions of Figs. 4 and 5 to make this selection criterion explicit and consistent with the description in the main text.

Revised Fig. 4 caption: "*Composite anomalies of 500-hPa geopotential (shading, m^2/s^2) and horizontal wave activity flux (WAF, vector, m^2/s^2) from October of the preceding year to January of the following year, based on winters when the standardized Cluster 1 MHWCI exceeds +1 standard deviation. The anomalous WAF flux is shown only when its magnitude is larger than 0.1 m^2/s^2.*"

Revised Fig. 5 caption: "*Composite anomalies of sea surface temperature (shading, ºC) and wind stress (vectors, N/m^2) from October of the preceding year to January of the following year, based on winters when the standardized Cluster 1 MHWCI exceeds +1 standard deviation*."

Line 105 – the reference for OSTIA is missing.

Response: We thank the reviewer for pointing this out. We have added the missing OSTIA reference to its first mention in the Data section.

L104-L106: "*This product is generated by the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) (Worsfold et al., 2024), which integrates multiple satellite observations and in situ measurements, and covers the period 1982-2021.*"

Line 490 – this should say Figure 6 rather than Figure 5

Response: Thank you for pointing this out. The figure reference has been corrected from Fig. 5 to Fig. 6.

Line 508 – this should refer to Figure 7h rather than 7i.

Response: Thank you for pointing this out. The figure reference has been corrected from Fig. 7i to Fig. 7h.

Fig 11 – the downwards arrow next to MLD arrow is ambiguous, as it could be interpreted as the MLD going deeper, but it is actually the opposite. Some additional clarification in the caption might be helpful to the reader.

Response: We thank the reviewer for this helpful suggestion. We have modified the schematic label to use "MLD shoaling" to avoid ambiguity.