Reply to Reviewer 2

Dear Reviewer,

We want to thank you for your dedicated time to review our manuscript. Your input has helped improve the clarity and robustness of the document. The changes are marked in the manuscript, as well as the reply to your comments below (in blue) .

Review of Is the North West European Shelf becoming more stratified with the occurrence of marine heatwaves? by Wei Chen and Joanna Staneva

This works looks at an interesting process: the possible changes in stratification of the water column that may occur with the increasing frequency and intensity of marine heat waves. As such the works lacks to settle which temporal scales the authors are working with. Is the average stratification over the year, or the stratification surrounding a MHW event? It is not clear how long the enhanced stratification caused by a MHW event would last in a region subject to strong tidal currents. The authors find that indeed, stratification appears to be weakening, which may appear counter-intuitive but I think it stems from the temporal scale mentioned above.

Thank you for the comment. As depicted in Figure 3, the stratification is averaged over years (blue solid lines) and over summer periods (red solid lines). Recognizing that merely describing it in the figure caption is insufficient, we have augmented the figure descriptions in the revised manuscript. In the revised 'Results' section, we have added: "In this study, only annual mean and summer period (June to September) mean stratification are considered."

I am not a huge fan of questions in titles, and in this case, in which the answer appears to be negative, I would suggest to rephrase the title so that it is more informative.

We express our gratitude to the reviewer for the suggestion. The title is revised to: "Characteristics and Trends of Marine Heatwaves in the Northwest European Shelf and the Impacts on Density Stratification"

I include here below a few comments that could maybe help in improving this work.

Thank you!

The main comment, as mentioned above, would be to establish from the beginning at which temporal scales do the authors think the MHWs would have an effect on stratification, and perform tests at different time scales to assess how long the effects of MHWs are felt in the water column. As the place is limited I would suggest to cut on the part of the MHW

description, as there is already previous work on that on this region (e.g. Mohamed et al 2023) and focus more on the stratification part.

Thank you for the suggestion. In the updated manuscript, we have incorporated the referenced study, which was primarily focuses on the southern North Sea and not published when we initially submitted our work. We would like to clarify here that our study encompasses a comparative analysis of Marine Heatwaves' (MHWs) characteristics and trends across the entire Northwest European Shelf (NWES) over recent decades, including the Southern North Sea. This comprehensive analysis involves examining and comparing the features and trends of MHWs in different regions and their correlation with the trend of density stratification. Our findings reveal continuous and long-term MHWs in the southern North Sea. In contrast, the northern part of the NWES, particularly the shelf edge zone, experiences mostly intermittent and short-term MHWs.

To the best of our knowledge, our study represents the first comprehensive investigation into the patterns and trends of MHWs across the entire NWES and their connections with long-term density stratification features. Taking the southern North Sea as an example, a comparison between MHW patterns and trends (Figure 2) and stratification patterns and trends (Figure 4) shows no clear density trends, even as MHWs become longer and more frequent. Therefore, we believe that including the entire NWES and analyzing patterns and trends in different regions is essential for assessing MHW impacts on stratification trends across these diverse areas.

Detailed comments:

The Abstract contains a last part with too general wording (starting at "The outcomes of this research transcend theoretical confines...") that I don't think belong to an abstract (-> Conclusion?)

Thank you for this suggestion. We moved this part to the conclusion.

line 67: 1982 - 2022 I guess?

We update the texsts, which clarified this issue.

line 178: salinity is related to salt and freshwater discharges. But in figure 4, last row, there is no signal of the many rivers (Scheldt-Rhine-Meuse, Thames, Elbe?) that flow into the North Sea. How is this possible? It may be that the signal is too weak compared to the offshore signals (Norwegian coast, Atlantic Sea), so maybe it would be good to limit these figures to the North Sea Shelf. Otherwise it is only the offshore features that can be discussed.

Indeed, the reviewer is correct that the signal in the Norwegian and the Atlantic Sea is too strong compared to the shelf sea. We agree with the reviewer to mask these areas in the revision and minimize the range for contour plots. The updated plots (see below as well as in the revised manuscript) clearly demonstrate the impact of the rivers (e.g., the Rhine River and the Elbe River) on the density stratification.

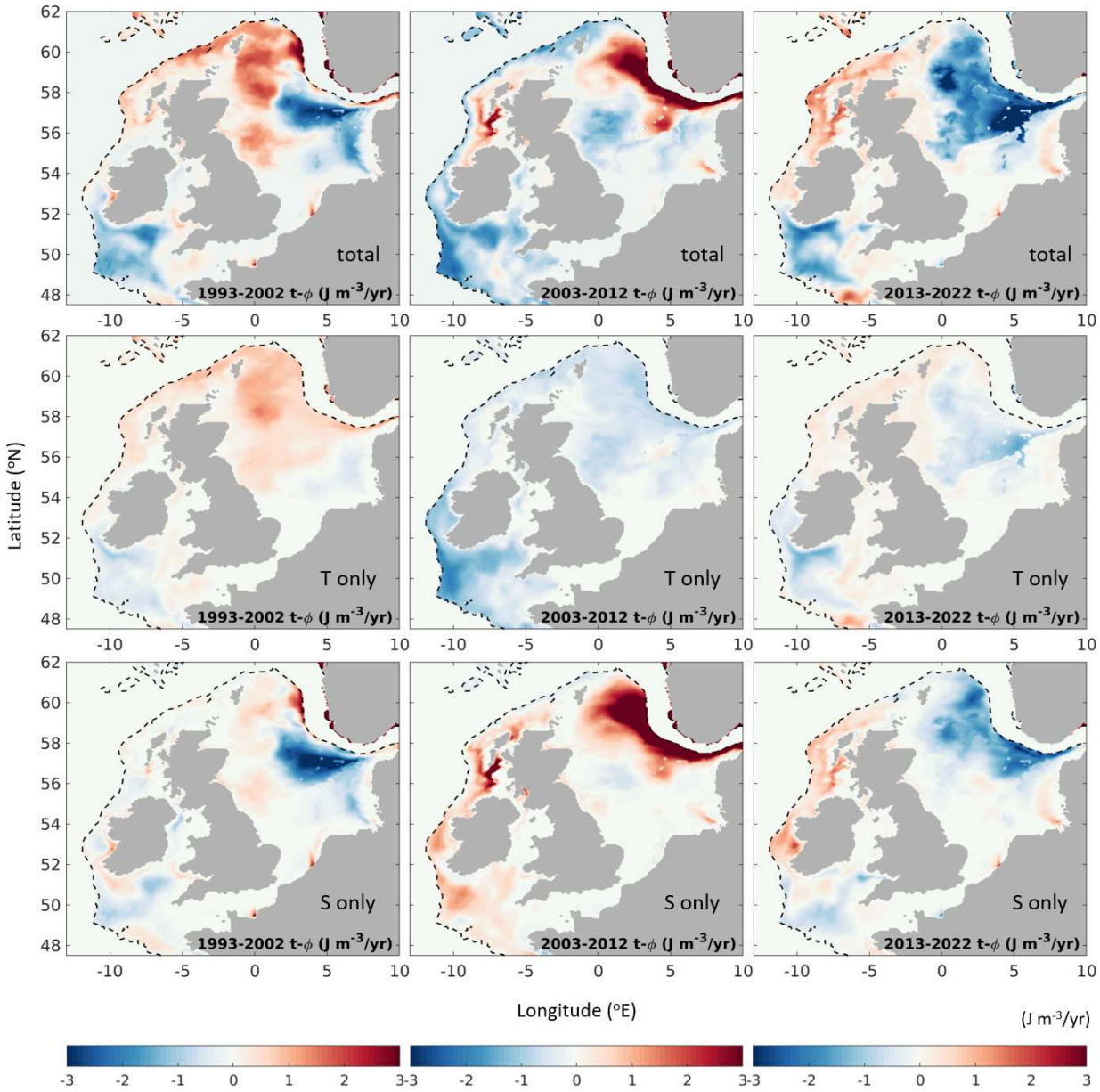

Figure 4. Trend of potential energy anomaly (ø, J m^{-3} yr-1) in the last 30 years. The first row (total) shows ø computed with eq. 1, where density depends on both temperature (T) and salinity (S) in the water column. The second and third row are similar as the first row but with density depends only on either T or S, respectively.

Figure 1. It is confusing that there are numbers in the panel a and b but they do not refer to the same things. The dotted line in panel a is difficult to see. Is the panel b a global assessment of MHWs in the whole domain? Not very informative as almost all signals are damped down by the averaging. Panels c to f: the individual lines are impossible to see.

In panel a, the black dotted line is replaced by white solid line. We change numbers in panel b to I, II, III, IV, …, to denote 7 MHW events. The subplot b illustrates the detection of MHW events near the Dogger Bank region (Region 1 in Figure 1a). We stated in the revised manuscript (First paragraph of section 3). We revised description in the caption for the updated manuscript. We further bolder individual lines in panels c to f.

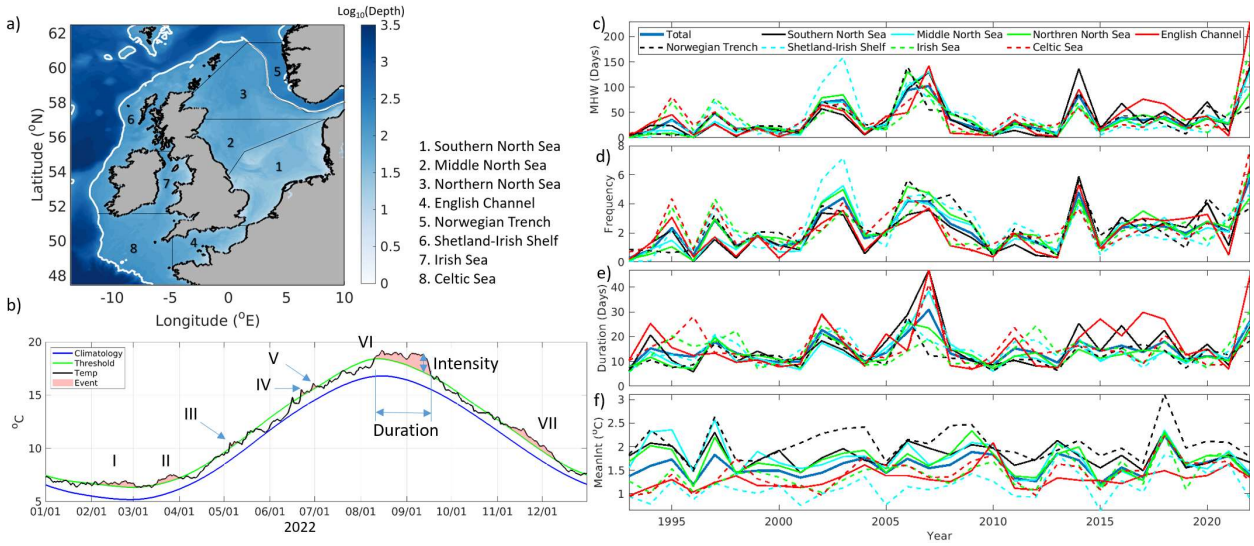

Figure 1: a) Map of North West European Shelf Sea with sub-region division (data from Table 1 ref. 1). Dashed curve indicates 200 m isobath. b) Detection of MHW events and their characteristics in 2022 (data from Table 1 ref. 1 & 2) near the Dogger Bank region in the southern North Sea (region 1 in panel a); c)-f) Variations of MHW characteristics between 1993 and 2022, with the bold solid curve indicating the mean of total subdomains of the NWES (daily SST data from Table 1 ref. 1 & 2).

Figure 3. This should be a central figure of this paper, as it presents the evolution of stratification over time, which is what the title claims the paper is about. But it is just slightly mentioned in the text, and in fact as the data are presented I think it is difficult to extract meaningful information. The text says "During summer, higher SST enhances the density stratification, leading to ø in summer approximately twice as high as the annual mean" but the lines in figure 3 (all panels) look quite homogeneous and no intra-annual variations are observed. I think the authors could get rid of figure 2 (and refer to results in literature) and expand figure 3 in two figures, maybe doing a short-term analysis of the effects of MHWs in the stratification and another with longer-term trends (i.e. your figure 3) but which would present the data more clearly: add grid lines, maybe a line showing the average value, and explain better what the green and black lines are (the caption says "The green and black dashed curves are similar as the red and blue curves, but for different subdomains" which I do not understand).

We decided to retain Figure 2 because we haven't found literature MHW features and trends in the entire North West European Shelf (NWES) region over the last 30 years. The most recently published paper (Mohamed et al., 2023) only studied MHWs and cold spells in the southern North Sea, which may not be representative of the entire NWES. As we clarified in response to your previous comment, there is no clear trend in stratification in the southern North Sea. We believe Figures 2 and 4 are essential for comparing patterns and trends in different regions. Moreover, the temporal variations in Figure 1c~f and Figure 2 only depict the subdomain-averaged annual mean characteristics of MHWs and Potential Energy Anomaly (PEA). However, they lack spatial patterns.

We revised the caption of Figure 3 for better description: 'Figure 3. Potential Energy Anomaly (ø, J m^{-3}) between 1993 and 2022. The solid curves denote the spatial mean PEA of the entire NWES domain. The red curves represent the summer period (June-July-August), and the blue curves represent the annual mean. The spatial mean PEA of different subdomains of the NWES (see Figure 1a) is indicated by dashed curves, with green and black dashed curves for the annual mean and summer mean, respectively.'

Figure 5. As for figure 4, in figure 5 variations at the Norwegian trench overshadow variations over the shelf. Also, the colorbar goes up to 2 but I would say 1.5 would be better?

Thank you. We updated Figure 5 with colorbar goes up to 1.5.

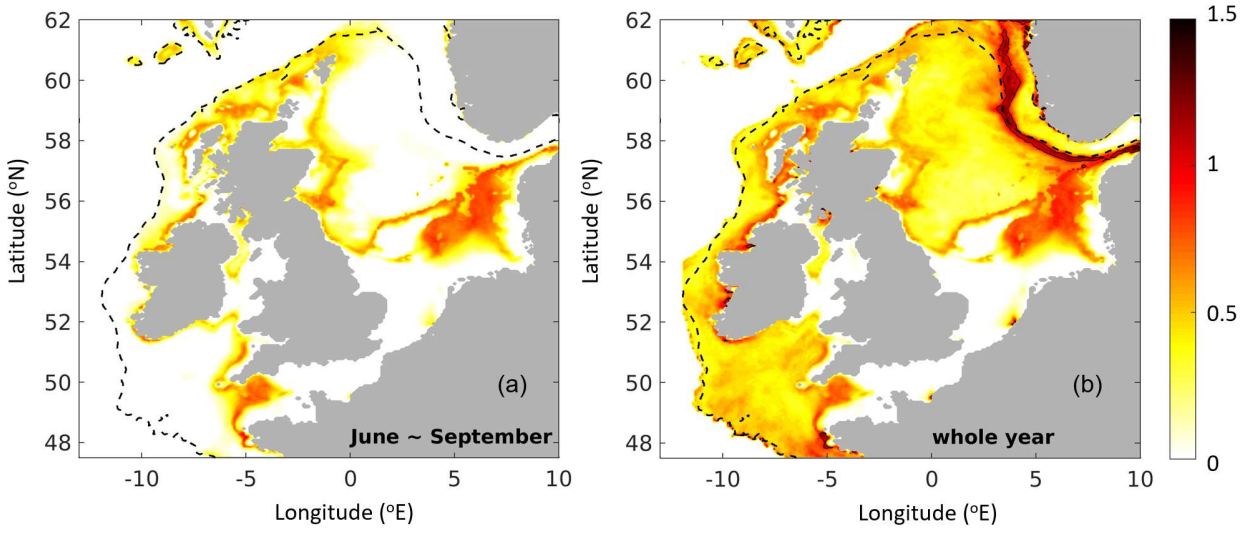

Figure 5. Ratio of the number of water stratification days to the number of MHW days for (a) June to September (summer period) and the whole year. The ratio is computed with Eq.4 using multi-year water temperature, salinity at different depths for 1992 to 2022 (Details are in Table 1 ref 1). The thin dashed line indicates the 200 m isobaths.