Response to reviewer one

Review of "Variations of marine heatwaves and cold spells in northwest Atlantic during 1993-2023"

The paper is well written (but I would probably have written "in *the* northwest Atlantic" in the title). I recommend a minor revision that would extend the discussion and conclusion a bit to the limits of using GLORYS as a MHW detection tool below the surface. The authors showed that GLORYS did not reproduce the high variability found in mooring data from the Halifax Line. It would therefore be valuable to learn which MHW metrics users should avoid using below the surface, such as probably count and frequency, and which are more reliable (perhaps total days).

R: We appreciate your helpful and detailed comments, and we addressed all of them in the revised manuscripts.

Regarding the discrepancy between GLORYS and mooring data, please note that this is at location 1 near the coast of Nova Scotia and may not apply to the whole Halifax Line. The reviewer's point is nevertheless important, so we added the following sentences in section 4: "GLORYS12V1 captures all parameters of observed bottom MHWs and the total days of bottom MCSs at this location. However GLORYS12V1 does not reproduce the intense cold spikes of observed bottom temperature and hence detects fewer and less intense bottom MCSs at this location. This can be attributed to the spatial resolution GLORYS12V1 that is insufficient to resolve the sharp spatial gradients of the Nova Scotia Current. Therefore near the coast of Nova Scotia, GLORYS12V1 underestimates the frequency and intensity of the bottom MCSs, although provides estimates of the total days in agreement with the mooring data. "

Substantive comments:

L141: "This can be attributed to the missing data in CMC SST due to the presence of sea ice in these regions."

Unclear. You just showed that CMC SST detected fewer events at location 2. Are you saying that proportionally to days available, CMC SST is on par with GLORYS at other sites? Also, if there's sea ice, presumably SST is near-freezing and not under a MHW?

R: Thank you for the insightful point. We added Fig. A3 in the Appendix and the following paragraph in section 3.1:

"In the southern and western Gulf of St Lawrence, the St. Lawrence Estuary, and on the Labrador and Newfoundland Shelf, CMC-SST has shorter total days than GLORYS12V1 (Figs. 1b and e). In the selected year 2011, Fig. 3A presents the SST time series at a location (52.8°N, 55.2°W) on the Labrador Shelf. The original CMC-SST data has a significant number of missing values from January to April during the presence of seasonal sea-ice (Fig. A3a), leading to the 90th threshold above of that derived from GLORYS12V1 (Figs. A3a and b). If the missing values of the original CMC-SST are filled with a freezing temperature of -1.8 °C, the resulting 90th threshold (Fig. A3c) and the total days of the detected MHWs are closer to that derived from GLORYS12V1 (Figs. A3b). Thus, the shorter MHW total days from CMC-

SST in regions with the presence of seasonal sea-ice are due the biased 90th threshold caused by the missing SST data values.”

L145: “location 2 shows much stronger SST variability”

Yes, and the reason is that it's at the Gulf Stream northern extension, with a succession and warm and cold oscillations and rings. This is mentioned later so omission of a reason here is strange, since reasons are provided for other regions.

R: We agree. We added the following sentence here as suggested: “At all the time scales, location 2 shows much stronger SST variability because it is located in the Scotian Slope where the water mass is affected by a succession of warm and cold oscillations and eddies.”

L149: “[spectral energy] at location 4 is higher at time scales longer than 100 days hence leading to higher total days.”

How so? Corresponding to higher average duration, yes, but total days?

R: Thank you for the insightful comment. The text is revised as: “That is, the spectral energy at location 3 is higher at time scales shorter than 100 days hence leading to higher MHW frequency, and at location 4 is higher at time scales longer than 100 days hence leading to longer durations. The higher total days at station 4 in 2012 are due to the long durations of warming above climatology in fall and winter.”

L158: “MHWs have lower frequency”

Frequency looks higher, comparing 1g to 1d.

R: We deleted the comparison of MHW and MCS frequencies.

L179: “However, mooring data show some intense cold spikes that are not captured by GLORYS.”

I was hoping for more on this in the discussion and conclusion. Mooring data shows much higher temporal variability, and also higher amplitude. Therefore MHW statistics of frequency and count would be very different based on mooring data than on GLORYS and likely not representative of reality. However perhaps GLORYS captures integrated statistics over the year well, such as total days?

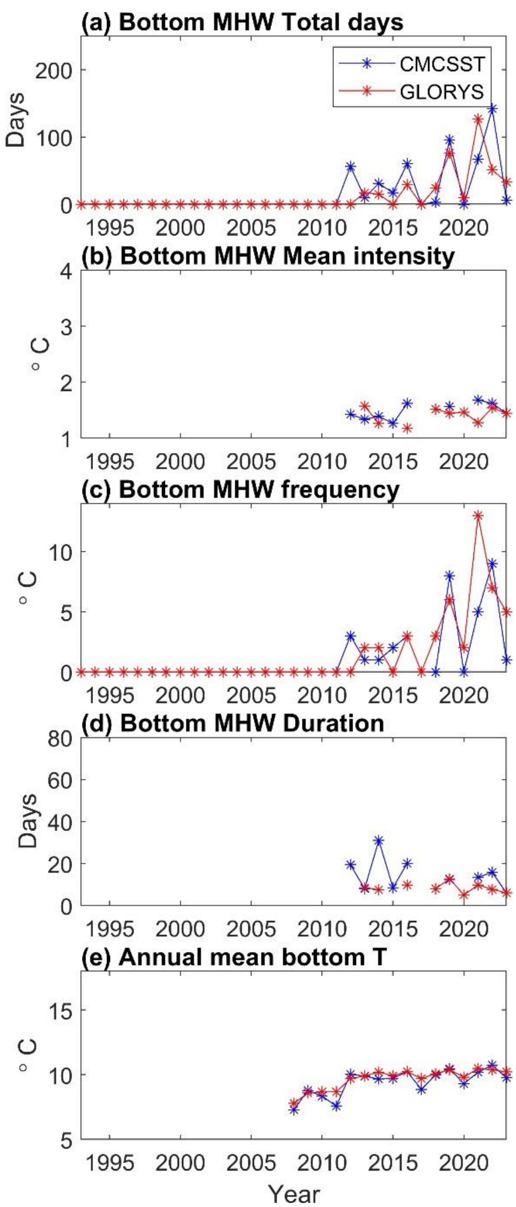
R: Please see the reply to the general comment.

L237: “the climatology of mooring data during the recent 16 years of 2008-2023 has a higher level than that of GLORYS during 30 years of 1993-2022. As a result, the mooring data obtains shorter and weaker bottom MHW events than GLORYS.”

This is easily tested by using either using the GLORYS climatology on mooring data, or (better) reprocessing the GLORYS MHWs using the 2008-2023 climatology range.

R: Indeed we tested the above hypothesis using the same reference period of 2008-2023. If the same reference period is used, the difference is largely reduced as shown in the Figure below.

Accordingly, the following sentences are added to the text: “As a result, the mooring data obtains shorter and weaker bottom MHW events than GLORYS12V1. If the same reference period of 2008-2023 is used, the difference in MHW parameters between mooring data and GLORYS12V1 is largely reduced. This suggests that the calculation of MHW/MCS parameters is strongly impacted by the duration chosen for computing the climatology, and whether detrending is applied, as discussed in Capotondi et al. (2024) and Smith et al. (2024).”



L249: “As a result, the bottom MHW total days frequently exceeded 200,”

This Implies MHWs may be not be a useful metric when water mass composition changes, and the system is permanently in a state of MHW. Useful discussion point?

R: We agree, and added the following sentence here: “This raises the question about how to define MHWs/MCSs in the presence of long-term trends or regime changes in ocean temperature, a point to be discussed in Section 4.”

L304: “1) shorter MHW total days in the Gulf of St. Lawrence and Labrador Shelf due to the missing SST data in the presence of ice,”

Is this a hypothesis or it is tested? (See above)

R: Please see the reply to L237. We changed the sentence to “shorter MHW total days in the Gulf of St. Lawrence and Labrador and Newfoundland Shelf are due to the higher threshold values caused by the missing SST data in the presence of ice,”

L313: “The 31 years (1993-2023) of GLORYS data enables the quantification of spatial variations, interannual variations and long-term trends of the water column and bottom MHW/MCS parameters for the first time in our study region.” But does it? Perhaps insist more on limits as GLORYS did not reproduce the high variability of the mooring. Discuss which MHW metrics are well reproduced, perhaps integrated total days?

R: We changed the sentences to “GLORYS12V1 captures all parameters of observed bottom MHWs and the total days of bottom MCSs at this location. However GLORYS12V1 does not reproduce the intense cold spikes of observed bottom temperature and hence detects fewer and less intense bottom MCSs at this location. This can be attributed to the spatial resolution GLORYS12V1 that is insufficient to resolve the sharp spatial gradients of the Nova Scotia Current. Therefore near the coast of Nova Scotia, GLORYS12V1 underestimates the frequency and intensity of the bottom MCSs, although provides estimates of the total days in agreement with the mooring data.“

Minor comments:

L14: on *the* Scotian Shelf

R: Fixed.

L16: “for the first time in our study region”. Actually, the following report was published just before this submission and contains a MHW section and one figure: Galbraith, P.S., Chassé, J., Shaw, J.-L., Dumas, J.

and Bourassa, M.-N. 2024. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2023. Can. Tech. Rep. Hydrogr. Ocean Sci. 378 : v + 91 p.

R: Thank you for the reference. The MHW section in this report is based on thermograph network daily mean temperatures, and provides a good reference to evaluate the MHWs derived from GLORYS in the Gulf of St. Lawrence. We deleted “for the first time” and cited the reference in section 3.1.

L44: Soontiens et al. (2024) is missing from bibliography. I presume it’s “this issue”.

R: We included Soontiens et al. (2024) citation.

L97: “The mooring is repositioned annually”: turned-over? redeployed?

R: We changed it to ”The mooring is redeployed annually”.

L111: “This study is going to focus”: will focus?

R: We changed it to “This study will focus”.

L117: “For surface MWHs, GLORYS and CMC SST data obtain overall similar magnitudes and spatial patterns of frequency, total days and mean intensity” Not so much the same for frequency; it's spatially homogenous on CMC and much higher over deep areas in GLORYS?

R: Thank you for the careful examination. The text is changed to “For surface MHWs, GLORYS12V1 and CMCSST data (Figs. 1c-f) obtain overall similar magnitudes and spatial patterns of mean intensity, but different magnitudes of frequency in deep waters and total days in the seasonally ice-covered areas. For frequency (Figs. 1a and d), both data obtain values of 1-2 events per year on the shelf; and in deep regions (near and beyond the 2000 m isobath) GLORYS12V1 and CMC-SST obtain higher and lower than 2.5 events per year, respectively.”

L120: “beyond *the* shelf break”

R: Fixed.

L121: “the Grand Banks for Newfoundland (GBN).” for? Why not just “Grand Banks”. I don’t recall ever seeing it written with “Newfoundland”.

R: We changed it to “Grand Banks”.

L124: “east of *the* Labrador Shelf”

R:Fixed.

Figure 1: The 1 to 7 labels are hard to see in some panels and should be described in the legend. I suggest a first single-panel figure showing the area, the 7 sites and all geographic areas named in the paper (e.g. Scotian Slope, Labrador Shelf, Grand Banks, Gulf of Maine, Scotian Shelf, Gulf of St. Lawrence)

Panel title should have the word "Surface" or "Bottom" to distinguish them (as in Fig. 4)

Add units to total days and intensity.

Figure 2: It's odd to have only one label on the x-axis for spectra, making it a guess as to the tic mark increments.

No need for "01/", just label the months between tic marks as J F M A M J J A S O N D

Figure 3: The d-f panels need better labels (and units) to include T or temperature.

The station "marked by a black triangle": is this location 7? If not, why not? If not, indicate it on the new first map.

R: Thank you for the suggestion. We updated Figures 1-3 and the captions accordingly.

L198: "a section extending off the coast from Halifax between stations 1 and 2": add: referred to as the Halifax Line within the AZMP.

R: We updated the text accordingly.

L206: "and in 1998 and 2012, respectively" add: "respectively cold and warm years throughout the water column (Hebert et al 2023)"

I presume you selected these two years for that reason…

R: We added the suggested text.

L209: "influenced by variations in the *outflowing* Gulf of St. Lawrence *waters*"

R: Thank you for the precise description. We added it to the text.

L238: "higher level": replace by "higher average temperature"

R: We updated the text.

L256: “Hebert et al, 2013” should read 2023. Note that the latest report is out: Hebert, D., Layton, C., Brickman, D., and Galbraith, P.S. 2024. Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2023. Can. Tech. Rep. Hydrogr. Ocean Sci. 380: vi + 71 p.

R: The citation here should be Hebert et al. (2013) because it reported that 2012 was the warmest of 43 years, with an averaged normalized anomaly of +2.8 SD relative to the 1981-2010 period.

The reference of Hebert et al. (2023) was missing from the reference list, and we now included it.

Table 2 : Add units within table (e.g. to linear trends).

Correlations with observations: What surface observations? The mooring presumably doesn't go to the surface. Main text infers it's CMC SST rather than observations. I wouldn’t classify them as direct observations but a reanalysis. Just clarify that you are referring to CMC SST.

R: We added units within the table, and also clarified the definitions of the correlations.

Response to reviewer two

Review of "Variations of marine heatwaves and cold spells in northwest Atlantic during 1993-2023"

This paper uses a high-resolution ocean reanalysis (GLORYS), a sea surface temperature dataset combining in situ and remote sensed observations, and data from moorings to examine the characteristics of marine heatwaves (MHWs) and Marine Cold Spells (MCSs) throughout the water column. While other studies have examined ocean extremes in this region, the combination of different data sources and the analysis of the depth-structure of the anomalies makes this paper novel and useful.

However, there are several aspects in which the paper could be improved.

R: We thank the reviewer for encouragement, and also the detailed and helpful comments to improve the manuscript.

Main comments:

The region of interest is characterized by complex topography and ocean circulation components. In the paper reference is made to different areas of the domain, which most readers may not be familiar with. Thus, I would suggest to include a figure that illustrates the various topographic features mentioned in the paper to orient the readers. Some bathymetric lines should also be indicated. Using that map, I would suggest starting with a short description of the main features of the circulation, which can then be used to explain differences in MHW characteristics in different sub-regions, especially their subsurface structure.

R: Thank you for the suggestion. We included names of geographic areas in Figure 1a, and added 100 m isobaths to all panels of Figure 1 to show topographic features on the shelf. We added a description of the main features of the circulation, and the influencing factors of water mass properties in different sub-regions of the study area, to the last paragraph of the Introduction.

The paper identifies some interesting interannual variations in MHW characteristics, but no attempt is made to explain their origin. While an in-depth assessment of the drivers of this variability is clearly beyond the scope of this paper, some hypotheses and discussion of their possible origin based on published literature would bring more depth to this analysis. I have some suggestions in one of the itemized comments below.

R: We appreciate the reviewer's suggestion to discuss possible drivers of interannual variations in MHW characteristics based on published papers. We make efforts to address this in the revised manuscript.

Itemized comments:

Lines 39-40. See also the recent review paper by Capotondi et al. (2024), which provides an updated discussion of the local and remote drivers of MHW in different areas of the world.

R: Thank you for the reference. We included this new reference.

Line 40. Remote drivers have been identified and discussed in many regions of the world. Since here only the Northwest Pacific is mentioned, I would start with “For example, in the Northwest Pacific….”

R: Thanks. Revised accordingly.

Line 51. I would suggest rephrasing “significant in the water column and at sea bottom” with “with large anomalies throughout the water column and at the sea bottom.”

R: We rephrased the sentence.

Line 57. “increasing” should be “increase”.

R: It was corrected.

Line 66. The reference Collins et al. 2019 is missing from the reference list.

R: The reference is added.

Line 72. “in Northwest Atlantic” should be “in the Northwest Atlantic”.

R: It was corrected.

Line 83. The acronym CMEMS needs to be defined.

R: We deleted the acronym CMEMS.

Lines 86-88. Which period is covered by the CMC SST data?

R: We changed the sentence to “Products ref. no. 2 during 1993-2016 and no. 3 during 2017-2023 ...”

Line 111. To be precise you are saying here that “the mean intensity of each event is the mean SST anomaly during that event”, correct? The yearly intensity is the average of the intensities of events during that year? This needs to be clearly stated.

R: Thank you for helping us clarify the definition. We changed the definition to “The intensity of each event is the mean SST anomaly during that event. The mean intensity is the average of the intensities of events during that year.”

Line 113. “is roughly”. Is this the way duration is computed? Please be precise.

R: Following Hobday et al. (2016), we redefined the duration. The duration of each MHW (MCS) event is defined as the period over which the temperature is greater (lower) than the seasonally varying threshold value.

Section 2.2. It looks like no detrending is applied to the data in this study, so that the events detected following the Hobday et al. (2016) definition may include the trend. There has been a lot of discussion in the MHW community on the definition of MHWs in the presence of a trend signal (see Smith et al. 2024, for a recent summary of the discussion and related recommendations). The trend signal can be expected to be large in this region (e.g., Xu et al. 2022), so it would be important to provide some estimate of the relative contribution of the trend vs. internal variability in the intensity and duration of the MHWs detected over this region. Specifically, how the results would change if the data were detrended?

R: Thank you for the reference. We clarified in the section 2.2 that “In this study, no detrending is applied to the temperature data prior to the MHW/MCS analysis.” We included the reference in the conclusion section. As discussion in section 3.3, frequency and total days of MHW/MCS show significant linear trends, corresponding to the long-term trends of temperatures.

Section 3.1. This section refers to Labrador Shelf, Grand Banks for Newfoundland (GBN), Gulf of Maine, Scotian Shelf, Gulf of St. Lawrence, etc. From Fig. 1, it is not clear where these places are. As mentioned in my main comment, having an initial figure that shows the location of these regions, would be very helpful.

R: Thank you for the suggestion. We added location names to Fig. 1a.

Line 124. “east of Labrador Shelf” should be “east of the Labrador Shelf”.

R: Corrected.

Caption of Figure 1. Please state what the asterisks and the numbers are. Also, specify what the frequency is (number of MHWs per year?), and the units for intensity.

R: We modified the caption of Fig. 1 accordingly.

Line 129. It would be good to distinguish the two isobaths. It is hard to know which is which.

R: We now use lines with different colors to distinguish them.

Line 137. Better to change “obtains” to “achieves”.

Line 138. “less than” -> “shorter than”

Line 141. “obtains’ does not seem the right word. What about just “has”.

Line 183. “lower” should be “shorter”.

R: Thank you. These are all revised.

Lines 193-194. Where are we supposed to see the black triangle along the Halifax line?

R: We changed it to solid dark triangle in panels a-f.

Line 201. “NHW” should be “MHW”

R: We fixed the typo.

Line 206. Where is the Emerald Basin located, and what determined the choice of years 1998 and 2012?

R: Emeral Basin is now named in Fig. 3a-c. We chose 1998 and 2012 because they are respectively cold and warm years throughout the water column (Hebert et al., 2023).

Line 207. What do you mean with “mean depth interface”? Please be more specific.

R: We changed it to 50 m.

Line 209. Which type of variations are those in the Gulf of St. Lawrence? And why are they important?

R: The sentence is revised to “near the coast are also influenced by the outflowing waters from the Gulf of St. Lawrence with strong seasonal and interannual variations in temperature and salinity (Umoh and Thompson, 1994; Dever et al., 2016).”

Lines 212-213. What do you mean with “downward penetration of the upper layer”? Are you talking about the downward penetration of the surface anomalies?

R: Indeed, the text is revised to “the downward penetration of the surface anomalies driven by surface winds and mixing ”.

Lines 213-214. “lateral advection of water masses”. Are the currents flowing at these depths? The role of advection in the subsurface structure of MHWs and MCSs should be related more precisely to the nature of the circulation.

R: Thank you for the suggestion. We changed the sentence to “On the other hand, this layer is also influenced by the lateral advection of water masses **carried by the horizontal currents**, ….”

Lines 216-217. It is not clear what “resulting to the horizontal transition of the depth-range of mid-depth layer…” means. Please explain.

R: We changed it to “resulting in the depth range of the mid-depth layer getting smaller from near the coast to the Emerald Bank. ”

Line 219. Are the interannual variations inferred from the difference between 1998 and 2012? If this is the case, this should be stated explicitly, e.g., “…but strong interannual variations, as it can be inferred from the differences between SST sections in 1998 and 2012.” Also the intrusions of offshore waters happening at these depths?

R: Thank you for the suggestion. We changed the sentence to “The deep layer below 130 m depth in the Emerald Basin (Fig. 3g) presents weak seasonal variations with a near constant temperature of 10ºC. However, this layer became colder in 1998 and warmer in 2012 than the climatology (Figs. 3h-i), suggesting strong interannual variations of temperatures in this layer.” The following sentence says “The temperature variations in this deep layer are mainly caused by the intrusion of the offshore water (Dever et al., 2016).”

Lines 236-239. The differences in climatology between GLORYS and the mooring data underscore the importance of the baseline chosen for computing the climatology, and whether detrending is applied, as discussed in Capotondi et al. (2024) and Smith et al. (2024).

R: Thank you for the references and important point. The text in second paragraph of section 3.3 is revised as: “While the two datasets show similar values and increasing trends in the bottom temperatures, the climatology of mooring data during the 16 years of 2008-2023 has a higher averaged temperature than that of GLORYS12V1 during 30 years of 1993-2022 (Fig. 4j). As a result, the mooring data obtains shorter and weaker bottom MHW events than GLORYS12V1. If the same reference period of 2008-20023 is used, the difference in MHW parameters between mooring data and GLORYS12V1 is largely reduced. This suggests that the calculation of MHW/MCS parameters is strongly impacted by the duration chosen for computing the climatology, and whether detrending is applied, as discussed in Capotondi et al. (2024) and Smith et al. (2024).”

Line 268. Can the advection of warm water from the Scotian Shelf be expected to be found in the depth range of the observed warming?

R: The text is revised as “Below the upper layer directly influenced by surface forcing, the warming in 2012 can be attributed to advection over the Scotian Shelf between 30-50 m, the advection of anomalously warm slope water combined with the reduced contribution of the cold water from the Gulf of St Lawrence or the inner Labrador Shelf between 50-100m, and the anomalously warm slope water being advected onto the shelf between 100-200 m. (Dever et al., 2016).”

Line 283. Casey et al. 2024 is missing from the reference list.

R: It is now cited.

Section 3.3. The interannual variations discussed in this section are very interesting, but no attempt is made here to explain what may cause variability at these timescales. El Niño Southern Oscillation is the strongest mode of variability on interannual timescales. Indeed, the years with the largest number of total MHW days in Fig. 4, as described in the text, seem to correspond to La Nina events in the equatorial Pacific, while MCSs seem to slightly follow El Niño events. This correspondence is in line with recent funding by Gregory et al. (2024), who examined the association between ENSO flavors and MHW globally using long time series of synthetic data. They do find that La Niña events in the equatorial Pacific tend to be associated with warm conditions in the Northwest Atlantic, although no causal relationship was investigated in that study. While an exploration of these connections is clearly beyond the scope of this study, these points could be included in the Discussion section as motivation for future work.

R: We thank the reviewer for this important suggestion. We added the following discussions in the third paragraph of section 4: "Further studies are needed to link variations of ocean temperature and MHW/MCS parameters in the Northwest Atlantic, at interannual and longer time scales, to large-scale ocean-atmosphere processes. For example, using long time series of synthetic data, Gregory et al. (2024) recently examined connections between El Niño-Southern Oscillations and variations of MHWs globally, and identified a linkage between La Niña events in the equatorial Pacific and warm conditions in the Northwest Atlantic. Further studies along this line are important for developing predictions of MHWs and MCSs in the future. "

Line 307. Better to say "present" than "possess".

R: Revised as suggested.

Lines 348-357. This discussion should be included in the Methods section (section 2.2), rather than in the Conclusions section, as the authors need to justify the choice made for their MHW and MCS definition. Also, the papers by Smith et al. (2024) and Capotondi et al. (2024) provide a more recent update on the baseline discussion. As I mentioned in one of my previous comments, it would be useful to see how the results presented in this paper would change if the data were detrended.

R: In the revised manuscript, we add the following sentences in section 2.2: "No detrending is applied to the temperature data prior to the MHW/MCS analysis because we want to maintain the consistency and be able to compare with the results of other studies in the Northwest Atlantic (Galbraith et al., 2023; Soontiens et al., 2025), and to emphasize the effects of ocean warming on the changing characteristics of MHWs/MCSs.". We keep the last paragraph of section 4 as a discussion for further work, ended with "In the present study, the long-term warming trend is retained in defining the water temperature climatology and the detection of MHWs and MCSs, while in the future we may explore other definitions when investigating the impacts of MHWs and MCSs on marine ecosystems and fisheries".

References

Capotondi, A., et al. 2024: A Global Overview of Marine Heatwaves in a Changing Climate, Communications Earth & Environment, 5, https://www.nature.com/articles/s43247-024-01806-9

Gregory, C., et al. 2024: Global Marine Heatwaves under Different Flavors of ENSO. Geophys. Res. Lett., 51, e2024GL110399, https://doi.org/10.1029/2024GL110399.

Smith et al., 2024: Baseline Matters: Challenges and Implications of Different Marine Heatwaves Baselines. Progr. Oceanogr., doi: https://doi.org/10.1016/j.pocean.2024.103404.

Xu, T. et al., 2022: An increase in marine heatwaves without significant changes in surface ocean temperature variability. Nat. Comm., 13, https://www.nature.com/articles/s41467-022-34934-x

Reply to reviewer three

General comments:

Using three different types of data including satellite sea surface temperature (SST), ocean reanalysis, and in situ observations, this study explores the long-term variations of the historical surface, subsurface, and bottom MHW/MCS over the northwest Atlantic. The results show the unique spatial features of the MHW/MCS events and their close relationship with the SST variations. Furthermore, possible mechanisms related to the interannual variations are evaluated. As mentioned by the authors, this is the first research focus on the long-term variations of the subsurface MHW/MCS over the study domain, which is worth publishing. However, at least one round of major revisions is needed before publication.

There are many basic errors in the content and figures, including, but not limited to, missing references of citations, lack of explanations of some definitions and data processing procedures. Personally, I think there is not enough consideration for the reading experience of readers who are not familiar with MHWs and the study area, making it difficult to interpret the detailed results without searching for the exact locations of areas and some concepts. In my personal opinion, it reads more like a preliminary draft than a manuscript ready for publication. More importantly, there is a lack of internal coherence as to why these results and plots were chosen, a core idea that ties everything together and is worth emphasizing in the title. The manuscript would be more logically readable if these issues were thoughtfully addressed.

R: We would like to thank the reviewer for the detailed and constructive comments. One main reason for not including sufficient details is the length limitation of the Copernicus Marine Service Ocean State Report. But, we fully agree that readability is important and we made extensive revisions of the manuscript with the guidance of comments from this and the other two reviewers. We considered the reviewer's suggestion to revise the paper title, but decided to keep the original one for the reason in response to comment on Line 338-340 below.

Specific comments:

Abstract:

There should be detailed information in the abstract, but perhaps not too much. I would prefer to read more summary, conclusion, or implication sentences instead, but this is a comment rather than a suggestion.

R: Thank you for this nice suggestion about the focus of the abstract, The abstract is revised accordingly.

Introduction:

Line 44-45: The existence of the last sentence makes me expect the content related to the MHW prediction in the next paragraph. However, it was related to the impacts of MHW. Therefore, I suggest changing the subject of this sentence to make a more logical connection, e.g. "With these identified physical drivers that trigger and maintain the events, MHWs could persist and induce severe impacts on marine ecosystems".

R: The concluding sentence of the first paragraph of Introduction is revised as "Identifying the physical drivers that trigger and maintain the MHWs (MCSs) is important for understanding and predicting the variations if these events and their impacts on marine ecosystems."

There is a major issue with the citations in the introduction, many papers cited here are not listed in the reference, at least from what I have checked, including but not limited to the (Collins et al., 2019) on line 36, (Soontiens et al., 2024) on line 44, and (Korus, 2024) on line 51. Please correct this issue and carefully check all citations in the manuscript.

R: We apologize for not checking this carefully before the submission. All citations are checked and reformatted.

Line 71-72: As the authors mentioned in the abstract, this study is the first long-term study of MHW/MCS in the subsurface of the Northwest Atlantic. I am just wondering if there is any case study of surface MHW or MCS in a similar region, and if the answer is yes, could you briefly introduce the impact of these previous events here to give the audience a first impression of the study area and thus emphasize the importance of this study. A map introducing the study area with the names of the individual geographical areas is also helpful for the audience in interpreting the contents of the results section.

R: Thank you for the suggestion. We included geographic names in Fig. 1a. Examples for impacts of previous events in our study region are added in the second paragraph of Introduction.

Datasets and analysis methods:

Line 103-104: If I remember correctly, Hobday et al. only define MHWs using the 90th percentile. There is another paper that follows his scheme and uses the 10th percentile for MCS. It is better to cite this paper for the definition of MCS.

R: Schlegel et al. (2017) defined the MCS as anomalously cold water events, similar to the MHW definition by Hobday et al. (2016). We cited Schlegel et al. (2017) at start of section 2.2.

Results:

Line 117-118: Compared to the MHW frequency and mean intensity, I could not identify the maps of MHW total days (Fig 1b and 1e) derived from CMCSST and GLORYS are with similar magnitudes over the northern regions, better to exclude these areas in the corresponding contents. And, if possible, longitude and latitude could be provided for a clear location of the sub-region when first mentioned in the contents.

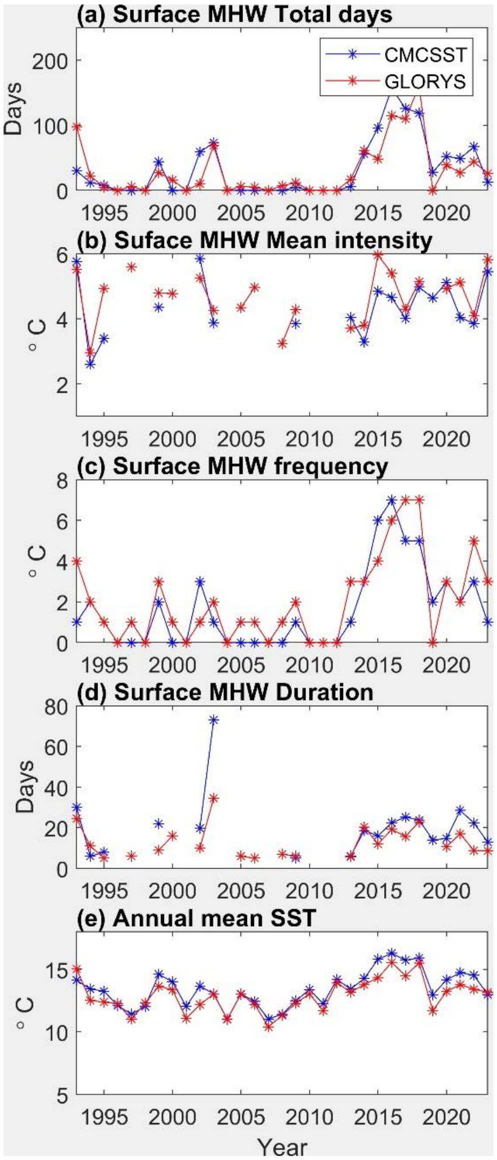
R: The first paragraph of section 3.1 is revised, with the help of geographic locations denoted on Fig 1a.

Figure 1: Locations 1-7 with detailed information such as the latitude and longitude should be provided in the figure caption. And please add the units for the color bars.

R: The information is now provided in the figure caption.

Figure 2: I am curious about how these years were selected, any criteria? If there is a selection process, could the authors explain it in the methods section? For the spectra plots, the x-axis is missing the small tick labels that show values other than 10-2.

R: In the second paragraph of section 3.1, we add "The selection of years is based on annual time series of the MHW parameters at these locations (not shown), ensuring that the differences in the MHW parameters between the left and middle columns are consistent with the 1993-2022 averaged statistics shown in Fig. 1." For example, to explain why MHWs are detected more frequently using GLORYS than CMC-SST at location 2, we choose year 2023 based on the annual MHW frequency shown in panel c of the figure below. In the right column of Fig.2, the spectra plots show more horizontal tick labels.

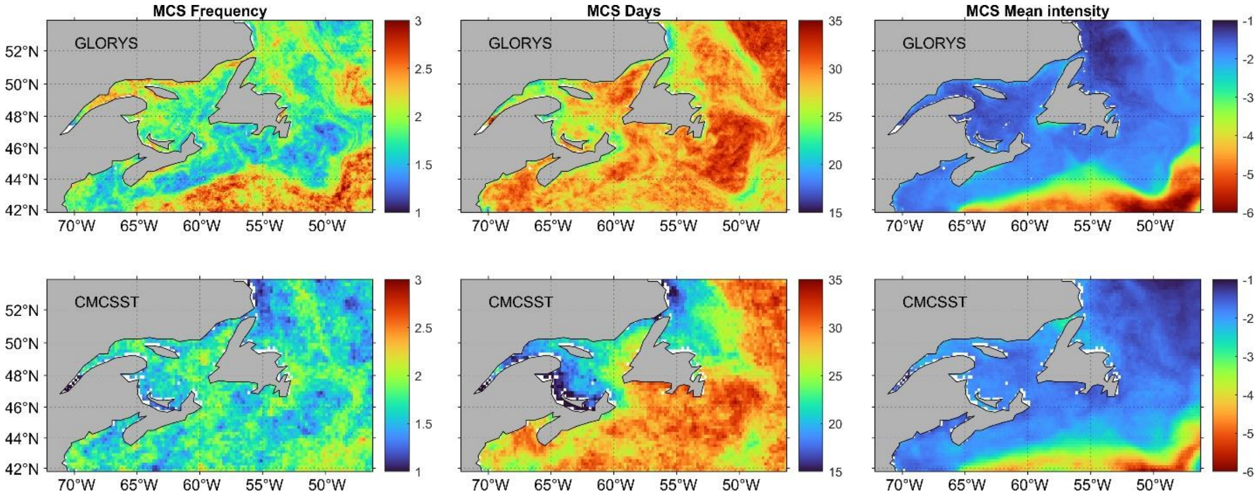


Line 140: I guess these are the areas where I mentioned in previous comments (line 117-118) that show large differences, as I do not know these regions. So please add the names of these regions on a map as suggested by the comments on line 71.

R: The names are added to Figure 1a.

Line 156-157: I understand why the MSCs are compared with the MHWs, as they are counterparts by definition, but why not show the results of the MCSs derived from the CMCSST? Are they similar to those from the GLORYS data?

R: In the last paragraph of section 3.1 we add: “The MCS parameters derived from CMC-SST (not shown) is also similar with the surface MHW parameters derived from GLORYS12V1 (Figs. 1a-c).” Figure below directly compares the MCS parameters derived from CMC-SST (not presented in the manuscript) and GLORYS12V1.



Line 160-162: It is quite interesting that skewness impacts the identification of MCS and MHW, so do the authors think that if they used the median as the climatological values instead of the mean, the results would be more symmetric?

R: At location 2 (Figure A1b) the median is smaller than the mean. If we use the median as the climatology, more and stronger MHWs, and less and weaker MCSs, will be detected than using the mean as the climatology. This will lead to more evident asymmetry between MHWs and MCSs.

Line 166-167: I assume there is no definition of bottom MHWs in the methods session, and it would be helpful to the audience if this was clarified.

R: We added the following sentence at the start of section 2.2: “We use the SST data to compute the surface MHW and MCS parameters, and the temperature at ocean floor to compute the bottom MHW and MCS parameters.”

Figure 3: As in Figure 1, please add the units and do not split the plots into two figures, even if they cross pages.

R: We added the units to the caption of Figure 3 and grouped all panels together.

Line 197-198: Why this cross-section is chosen to illustrate the features of subsurface MHW/MCS? How about other locations?

R: The reason for choosing this cross-section is given by the following added text: This cross-section, referred to as the Halifax Line, has been regularly occupied by the AZMP over multiple decades thus proving extensive observed hydrographic data to assess the quality of model-based data such as GLORYS12V1."

Line 216-217: A bit of confusion in this sentence. What exactly is the transition of the depth range? Getting thinner or thicker?

R: The sentence is now rephrased to "The contributions of the lateral advection vary from the coast to offshore, resulting in the depth range of the mid-depth layer getting smaller from near the coast to the Emerald Bank."

Line 219: I couldn't understand how the existence of interannual variability in the ocean bottom can be inferred from the climatology and two years of data in Figures 3g-i? Could the authors be more specific?

R: We changed the sentence to "The deep layer below 130 m depth in the Emerald Basin (Fig. 3g) presents weak seasonal variations with a near constant temperature of 10ºC. However, this layer became colder (warmer) than the climatology in 1998 (2012) (Figs. 3h-i), suggesting strong interannual variations of temperatures in this layer. "

Line 245-246: As the MHW intensity values are missing in some years, a bar plot may be more appropriate to show the mean intensity rather than a line plot, which mainly emphasizes the continuity of the data.

R: Thank you for the suggestion. Figure 4 is updated using bar plot for intensity.

Figure 4: If the two columns show different data, it might be better to distinguish the lines with different color groups, as the legend is only shown in the top two plots. Also, I personally prefer to use the letters instead of the row number in the figure caption, but it is up to the authors to decide.

R: Thank you for the suggestion. We revised Fig 4 to use different line types to distinguish CMC-SST and mooring data and use the letters in figure caption.

Conclusions and discussions:

Line 338-340: I personally think this is perhaps a unique and interesting point in the study area and worth emphasizing in the title, e.g. "Regime shifted bottom MHW and MCS under the warming ocean in the northwest Atlantic".

R: We agree with the reviewer that revealing the regime shift of bottom MHW and MCS is a significant aspect of this study. However, we think the other aspects of the space-time variations of MHW and MCS characteristics, e.g., the vertical distribution and differences between surface and bottom, are also valuable to report. We thus keep the original title of the paper.

Line 358-363: From my point of view, this paragraph is more expected in the introduction rather than in the discussion.

R: Thank you for the suggestion. We moved this paragraph to the second paragraph of Introduction: "The declining North Atlantic right whale population was related to the significant warming in the Gulf of Maine and the western Scotian Shelf over the recent decades (Meyer-Gutbrod et al., 2021). The impacts of the extreme cold (warm) event in 1998 (2012) on fishery species have also been studied. In 1998, shortly after the cold Labrador Slope Water replaced the Warm Slope Water, the catches of porbeagle shark and silver hake in the Emerald Basin dramatically declined (Drinkwater et al., 2002). The widespread 2012 warm event in the Northwest Atlantic, with large anomalies throughout the water column and at the sea bottom, had opposite effects on different commercial fisheries. It adversely impacted the snow crab juvenile stages, resulting in a temporary decrease in snow crab abundance on the western Scotian Shelf (Zisserson and Cook, 2017). In the Gulf of Maine, this warm event caused earlier inshore movement of lobsters in the spring, leading to enhanced lobster growth, an extended fishing season, and record landings (Mills et al., 2013). "

Technical corrections:

Line 23, 201, and 330: I suppose it is "uniform" instead of "unform".

R: Thank you for pointing out the typo. The related sentence is not deleted.

Line 206: Delete "and" before "in 1998…".

R: We modified the sentence to be " … for the mean climatology over 1993-2022, and in the cold and warm years of 1998 and 2012, respectively."

Line 254-255: Delete "each one" before "lasted 7 to 61 days".

R: We changed the sentence to "Both GLORYS12V1 and CMC-SST detected 7 MHW events with the duration ranging from 7 to 61 days."