Responses to Reviewer 2: Minor Corrections

Manuscript number: egusphere-2024-2210

Manuscript title: Subsurface manifestation of Marine Heatwaves in the South West Indian Ocean

- **In bold black: Reviewer 2**

- In plain blue: our responses

I congratulate the authors for the new version of the manuscript, in particular for the subsurface statistical analysis. The manuscript has greatly improved and in my view there are only a few outstanding issues before recommending publication. I list them below by line number (track changes version) and indicate two of them as important. I recommended «minor revision » because addressing the issues indicated below should be relatively quick and does not require necessarily new analysis or extensive discussion. However, without correctly addressing these points (in particular the two important issues of L257) the paper in my view is not ready for publication.

Dear Reviewer,

Thank you for your thoughtful feedback on the revised manuscript. We greatly appreciate your recognition of the improvements made, particularly with regard to the subsurface statistical analysis.
We have carefully addressed the outstanding minor issues and addressed each point carefully - including the two important concerns on line 257. Please note all changes list below by line are done so according to the line numbers from the track changes version of the revised manuscript.
We believe these revisions adequately address your concerns, and we look forward to your feedback. Thank you again for your valuable input.

L18 « these eddy corridors » : this expression to me is not very clear, especially for an abstract. A corridor is a narrow and long passage. In the context of the abstract its meaning is not unique, as it can be intended as some space between several eddies, in the vertical across individual eddies, along a narrow region at the basin scale where eddy presence is higher, etc. I would suggest to provide in the text a compact definition or ading one or two keywords to specify at least at which scale this corridor has to be intended.

In response to your suggestion, we have replaced the term "eddy corridors" with the phrase "regions of high eddy activity in the Mozambique Channel and southeast of Madagascar" to provide a clearer and more precise description. This revision specifies the geographical region of interest and avoids ambiguity regarding the scale or type of eddy feature. We hope this improves the clarity of the abstract.

Edited text: Was Line 18, Now Line 16
'Regions of high eddy activity in the Mozambique Channel and southeast of Madagascar.'

L60 « WBCs current system » : « C » meaning already « current », maybe « WBC system » ?

Thank you for noting this error. We have corrected it.

Edited text: Was Line 60, Now Line 55
'WBC system'

L61 Ramirez et al. not in the bibliography

Thank you for bringing this to our attention. The Ramirez et al. 2017 reference has now been added to the bibliography.

Edited text: line 567
Ramírez, F., Afán, I., Davis, L. S., and Chiaradia, A.: Climate impacts on global hot spots of marine biodiversity, Sci. Adv., 3, e1601198, https://doi.org/10.1126/sciadv.1601198, 2017.

L108, 145 and 193 : High resolution (0.25°). Today, I would not call a product at 0.25° resolution « high resolution ». High resolution altimetry corresponds more to the resolution of the novel SWOT satellite (about 2km) and high resolution SST to infrared products (in the km range). Instead of « high resolution » I would suggest the term « mesoscale resolving ».

We agree that the term "mesoscale resolving" is more appropriate for describing a 0.25° resolution in the context of modern altimetry and SST products. We have revised the text to replace "high resolution" with "mesoscale resolving" to better align with current terminology and to accurately convey the scale of the data.

Edited text: Was Line 108, 145 and 193, Now Line 99, 135, 195, 221 and 223
Replaced 'high resolution' with 'mesoscale resolving'.

L161-163 : subsurface warm temperature signal : I agree that the anomaly is likely to be warm in the presence of a surface marine heatwave, however, since this is a hypothesis to test, I would replace « subsurface warm temperature signal » with « subsurface anomaly temperature signal », so that no a priori assumption of a warm character of the anomaly is done in the Methods part.

Thank you for this suggestion. We have replaced "subsurface warm temperature signal" with "subsurface temperature anomaly" in the Methods section to avoid assuming the nature of the anomaly. This revision ensures that no a priori assumption of a warm character of the anomaly is done in the Methods section.

Edited text: Was Line 161 - 163, Now line 151:
"Subsurface warm temperature signal" replaced with "subsurface temperature anomaly"

L254-256 : What are the two percentages for non-MHW profiles ?

Non-MHW profiles were not included in our analysis, as our focus was specifically on understanding and characterising the depth extent of MHW events. Therefore, we do not provide corresponding percentages for non-MHW profiles. Investigating non-MHW profiles is beyond the scope of this study and would require additional statistical analysis which we do not think would enhance the results of our study significantly enough to justify the additional analysis required.

L257 (important issue): I am confused by the meaning of « subsurface » . Looking at figure 4a the large majority of profiles in MHWs have a maximum at 800m or deeper (they are dark blue), which looks to me surprisingly high. Can you confirm that the colorbar is correct? In this case, this is not consistent with your case studies analysis, in which there is no a single example of temperature anomaly maxima at 800m or higher. Something is wrong here, or possibly I am missing something.

Thank you for bringing this to our attention. It seems there has been a misunderstanding of what Fig 4a represents and we apologise for this confusion. The colour bar for Fig 4a does not indicate the depth of the maximum subsurface temperature anomaly, but rather the depth extent of the positive temperature anomaly that extends from the surface MHW signal down the water column. This confusion has brought to our attention that we also did not describe how this was identified in the Methods Section.
To provide clarity, we have stipulated in the methods section 2.4 that for each temperature anomaly profile (associated with surface-identified MHWs), the depth extent of the positive anomaly in the water column was identified. We have specifically defined both the depth extent of the positive temperature anomaly and the depth of the maximum warm subsurface temperature anomaly, as both are investigated. In accordance with this edit, we have updated Fig 4a's colourbar heading as well.
Furthermore, we acknowledge that the wording of the paragraph starting L257 may have contributed to this confusion and have refined the paragraph to provide a clearer and more precise interpretation of Fig. 4a. We hope this resolves the confusion and appreciate the opportunity to clarify. Please note that some of the text presenting changes made for this comment also include changes made in response to the next comment regarding the consideration of subsurface anomalies only when they persist below the mixed layer depth. This is further explained in more depth in response to the next comment.

<u>Edited text: Line 161 - 163 (Methods Section 2.4)</u>
"... three metrics for subsurface MHWs were identified: (1) the maximum depth extent (m) of the warm anomaly; (2) the maximum subsurface temperature anomaly (°C) and (3) the corresponding depth (m) of this maximum subsurface temperature anomaly."

<u>Line 231 – 243 (Results Section 3.2)</u>

"For each day and location where a MHW signal was detected over the XBT transect, all but two events exhibited warm temperature anomalies that extended from the surface down to the climatological MLD (47.15 m), with 68 % of them reaching down to 800 m. Furthermore, 80.25 % of the events experienced maximum temperature anomalies below the climatological MLD (47.15 m). Given that anomalies are considered subsurface if they extend below the MLD, these results suggest that the majority of surface-identified MHWs were associated with deep-reaching, subsurface-intensified warm anomalies. A significant relationship was found between the surface temperature anomalies and the maximum subsurface temperature anomalies ($r = 0.67$, p–value < 0.0001), as subsurface anomalies tend to increase with increasing surface anomalies (Fig. 4a). Furthermore, deeper MHW events, where the **maximum depth extent of the warm anomaly was greater than 500m**, tend to have warmer subsurface maximum temperature anomalies than shallower events. On average, events that extend deeper in the water column have surface temperature anomalies of 1.17°C and maximum subsurface anomalies of 2.27°C. Whereas shallower events, where the **maximum depth extent of the warm anomaly was less than 500m**, have, on average, surface temperature anomalies of 1.18°C and maximum subsurface temperature anomalies of 1.91°C. This observed depth–dependent pattern suggests that the depth extent of the subsurface temperature anomalies may play a role in modulating subsurface thermal responses to surface anomalies."

Line 259 - 260 (Fig 4 Figure caption)

"Figure 4: a) Scatter plot of surface temperature anomalies and maximum subsurface temperature anomalies where surface MHWs were identified. Colours indicate the maximum depth extent of the warm anomaly (m)."

L257 (important issue): The definition of « subsurface » should include only values starting below the mixed layer (even a rough estimation, like its climatological depth) in order to avoid to call « subsurface » a maximum that is just below the surface, and therefore may be higher than the surface value just because of noise. Please at least check that all the « subsurface » maxima are really subsurface, that is, their depth is at least below the mixed layer, and indicate this in the text.

Thank you for your careful consideration of the definition of "subsurface." We fully agree that only maxima occurring below the mixed layer should be classified as "subsurface". To ensure consistency, we calculated the mean climatological mixed layer depth (47.15 m). The maximum subsurface temperature anomalies were then noted below this mixed layer depth. This adjustment guarantees that all identified subsurface anomalies are truly below the mixed layer and not influenced by near-surface noise. The manuscript has been updated accordingly, with a clear definition included in the text (Methods Section 2.4 and in Results Section 3.2) and the Fig. 4 and Fig. 5 have been updated to only consider subsurface anomalies below 47.15 m.

Edited text: Line 152 - 160 (Methods Section 2.4)

"Warm temperature anomalies extending below surface-identified MHWs, were only considered subsurface if they extended below the mean climatological mixed layer depth (MLD).

The climatological MLD was calculated using the temperature threshold method, similar to the approach by De Boyer Montégut et al. (2004) and Elzahaby and Schaeffer (2009). The MLD was determined as:

$$MLD = \min \{z \mid T(z) < T(10) - 0.2°\,C\} \quad (2)$$

where T(z) represents temperature at depth z, and T(10) is the reference temperature at 10 m depth. The threshold temperature (0.2° C) and reference depth (10m) were chosen based on the recommendations of De Boyer Montégut et al. (2004). The final climatological MLD was obtained by averaging MLD values across the study region, providing a robust estimate of 47.15 m."

Edited text: Line 231 – 235

"For each day and location where a MHW signal was detected over the XBT transect, all but two events exhibited warm temperature anomalies that extended from the surface down to the climatological MLD (47.15 m), with 68% of them reaching down to 800 m. Furthermore, 80.25% of the events experienced maximum temperature anomalies below the climatological MLD (47.15 m). Given that anomalies are considered subsurface if they extend below the MLD, these results suggest that the majority of surface-identified MHWs were associated with deep-reaching, subsurface-intensified warm anomalies.”

L258-259 « Furthermore, deeper.. are more comparable (Fig. 4a). » I don’t see this quantitatively in Fig 4a. I have the impression that there are more « green/yellow » dots below the red lines, but a quantification of your statement (for instance max anomaly average for the maxima deeper than 500 m vs the average of the ones shallower than 500m) should be provided.

We appreciate your recommendation and agree that the addition of a quantitative comparison would further substantiate our statement. To address this, we have now included a quantification of the maximum subsurface temperature anomalies that extend below 500 m versus those temperature anomalies that are shallower than 500 m. This was quantified by determining the average surface and average maximum subsurface temperature anomaly for those anomalies that extend down to 500m (shallow events) and those temperature anomalies that extend between 500 – 800m depth. This analysis confirms that deeper subsurface anomalies are generally associated with warmer maximum subsurface anomalies, supporting our original statement. Please see our above response for the updated text and additional quantification.

<u>Edited text: Line 238 – 243</u>

“Furthermore, deeper MHW events, where the **maximum depth extent of the warm anomaly was greater than 500m**, tend to have warmer subsurface maximum temperature anomalies than shallower events. On average, events that extend deeper in the water column have surface temperature anomalies of 1.17°C and maximum subsurface anomalies of 2.27°C. Whereas shallower events, where the **maximum depth extent of the warm anomaly was less than 500m**, have, on average, surface temperature anomalies of 1.18°C and maximum subsurface temperature anomalies of 1.91°C. This observed depth–dependent pattern suggests that the depth extent of the subsurface temperature anomalies may play a role in modulating subsurface thermal responses to surface anomalies.”

Fig 5b : Again, I would consider « subsurface » only maxima that are deeper than the mixed layer.

Noted. We have also updated Fig. 5 to ensure that only maxima occurring below the mixed layer depth (set at 47.15 m, as explained in our response to L257) are considered "subsurface". This revision ensures consistency across the analysis and avoids misclassification of near-surface anomalies. The figure and corresponding text in the manuscript have been edited to account for this edit.

L389 : « The majority of the subsurface anomalies associated with MHWs extend to depths down to 800m, with maximum temperature anomalies occurring beneath the surface. » I don’t think you showed that in general the majority of subsurface anomalies extend down to 800m. This has been shown only for three case studies. Unless I’m wrong,

please correct this statement. I also noticed that in between the warm anomalies there are important cold anomalies. This suggest an alternating pattern of heat waves / cold spells. The authors may or may not want to elaborate on this point in the Discussion.

In results section 3.2 “Subsurface temperature anomaly properties associated with surface–identified MHWs” (line 232) we find that 68% of the warm subsurface anomalies have a maximum depth extent of 800m, also shown in Fig 4a, where the colour bar represents the ‘maximum depth extent of the warm anomaly’ for each temperature profile. We believe this is enough to justify our claim that, in general, the majority of the subsurface anomalies associated with MHWs extend to 800m.
Thank you for your observation of the alternating pattern of heatwaves/cold spells, which we agree is indeed an interesting characteristic of this region. However, the focus of this study is specifically on the warm anomalies associated with MHWs and, as such, cold spells were not investigated as part of this study. Since the main aims of this study were to characterise the subsurface extent of MHWs in the SWIO, we have chosen not to mention this observed alternating pattern. Cold spells in the Agulhas are the subject of our ongoing research.

References : Azarian et al. 2024 : I mention this paper in my previous review, however the authors have added Azarian et al. 2023. Azarian et al. 2023 talks about surface heat waves, the 2024 paper I was referring to (https://doi.org/10.1016/j.jmarsys.2023.103962) about some subsurface signature of marine heatwaves. This is a minor issue, the authors may leave as is now, or update the discussion with the 2024 paper.

Thank you for pointing this out. We cited the incorrect reference in the bibliography. We have now revised the manuscript to include the correct reference, Azarian et al. (2024), which aligns with the discussion on subsurface signatures of marine heatwaves.

<u>Edited Text: Line 440 – 442</u>

“Azarian, C., Bopp, L., Sallée, J.-B., Swart, S., Guinet, C., and d’Ovidio, F.: Marine heatwaves and global warming impacts on winter waters in the Southern Indian Ocean, Journal of Marine Systems, 243, 103962, https://doi.org/10.1016/j.jmarsys.2023.103962, 2024.”