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Peer Review File

A global overview of marine heatwaves in a changing climate

Corresponding Author: Dr Antonietta Capotondi

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

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Dear Dr Capotondi,

Your manuscript titled "A Global Overview of Marine Heatwaves in a Changing Climate" has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

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We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Dr Alireza Bahadori
Associate Editor
Communications Earth & Environment

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

Review of "A Global Overview of Marine Heatwaves in a Changing Climate" by Capotondi et al.

This manuscript presents a review of recent advances on Marine Heatwave (MHW) research, with an emphasis on the study of three-dimensional structure of MHWs. Other topics covered in the review are compound events and biogeochemical extremes and predictability of MHWs. There are also sections focused on defining MHws and about MHWs in a changing climate.

Given the huge number of publications that are being produced nowadays around the important topic of MHWs, these review works are necessary in order to discern the main lines of emerging results that are otherwise scattered. I therefore commend the authors for this effort. The review is written clearly and concisely, although there could be a reorganization of some of the sections with similar topics. I am thinking about the sections "Defining a marine heatwave" and "Marine heatwaves in a changing climate", which could come one after the other in the text, as well as "Compound and cascading events" and "Prediction of MHWs and associated biogeochemical extremes".

The observation of MHWs other than with satellite data remains difficult, as it happens with many events that can occur anytime, anywhere. Only institutions with a solid fleet of platforms (moored buoys, gliders, ship time etc) can dedicate the needed effort to carefully study a MHW, as depicted in the example given in box 2, and which is out of reach of many institutions. Given that MHWs can occur anywhere, and have far-reaching and cascading impacts, there needs to be a concerted effort to improve our global capacity to measure MHWs and the state of the ocean in general, and not only at the surface. A better knowledge of the state of the ocean at depth, including for example a sustained effort at deploying Deep Argo floats, will form the basis for better models and forecasts, and will allow for the understanding of future changes.

Another topic that I think requires attention is the detection of past MHW events, in order to understand how their rate and intensity is changing. Past assessments at depth can only be done through the use of reanalyses, but there are several reanalyses that provide diverging results for the state of the ocean in the past decades. Any MHW study that uses reanalyses should be done with an informed choice on the options available, and this is even more true for any variable other than temperature (i.e. for compound events), where the divergence (uncertainty) among model estimates is far greater.

The two above topics are, in my opinion, of great importance in MHW research, but are only briefly, if at all, mentioned in this work.

Detailed comments:

The starting 2 sentences of the manuscript "Marine heatwaves (MHWs) have dramatically impacted marine ecosystems and ecosystem services over large areas of the world oceans. In this paper, we review the recent substantial advances in this active area of research" seem to say that the paper focuses on the impact of MHWs on the ecosystem, and not on MHWs at large, but the latter is true.

Lines 162 to 168: in addition to the spatial and temporal resolution of the satellite SST datasets, the quality of the interpolated datasets if one is using level-4 SST data also has to be considered, as it is the actual resolution (minimum scales resolved by the dataset) which often differ from pixel size in these L4 estimates.

Line 219: I was somehow surprised by the mention of paleoclimate proxies in this section. These estimates of past climate lack the temporal and spatial resolution to effectively study MHWs, which are per definition short and localised. Reference 88 deals with with a time series from 1800 to present, which I would not classify as paleo. Reference 89 is about the present-day effect of MHWs in foraminifera, which as noted by the authors lack the temporal resolution in paleo time series to study MHWs in the past.

Line 248-249: "Advection-driven MHWs typically have a smaller surface area, but last longer [21] and reach deeper [104]". Reference 104 looks at one case study in Eastern Australia, so the sentence before should be modulated (i.e. may reach deeper), or additional evidence should be provided to maintain the assertiveness of this sentence.

Figure 2 shows a series of schemas on the evolution in time and space of MHWs, but some of them are perhaps too schematic, failing to show what the authors claim. For example, figure 2f is said to show Ekman pumping and effect of Rossby waves, and I fail to see any of these effects in this figure.

Figure 6 is said to show widespread ocean warming, result of heat absorbed by the ocean (line 476-477), but this figure shows projections of MHW changes in the coming decades.

Box 2. This box is mentioned in the text as "novel ideas for integrated observing systems". As far as I see it, this is a multiplatform study of a specific event, as there have been others to monitor for example, submesoscale variability in a region. But I fail to see what is novel with this approach, in the frame of MHW study. In addition, the data are shown, but there is no indication on how these data have helped monitor MHWs: maybe showing anomalies, or MHW status in the time series of panel e would be more adequate. A box showing the location of panel b should be included in panel a. What is the source of SST data in panel a? What do the Argo profiles show? Again, maybe anomalies should be shown in order to reinforce the value of these measures in the monitoring of MWHs. A useful discussion in this box would be how MHWs could be monitored using only partial observations. As I mentioned above, it is rare that such a vast amount of different data sources are available to everyone, and more often than not scientists have to perform their monitoring using only 1 or 2 of these kind of data, so what are the lessons learned from these exercises? What is the best strategy to monitor MHWs with few observations?

Reviewer #2 (Remarks to the Author):

Review of "A Global Overview of Marine Heatwaves in a Changing Climate”

Authors: Capotondi et al.

Recommendation: Minor Revisions

I have a positive opinion of this paper. There have been previous reviews of marine heatwaves (MHWs), as noted on line 84, but the present paper represents a meaningful contribution to the growing body of work on the topic. It includes a wealth of references and clear writing. My comments that follow represent not serious concerns but rather thoughts for the authors to consider in revision, without making the paper too much longer.

I feel there should be greater recognition that the processes responsible for the onset of MHWs are not necessarily the same as those responsible for their maintenance. This can be especially the case for MHWs that persist over multiple seasons. For example, and at least at middle and higher latitudes, anomalous insolation tends to be a much more important driver in summer rather than winter. Schmeisser et al. (JGR, 2019) represents an example of a paper dealing with both the onset and maintenance phases of the NE Pacific MHW of 2014-2016. On a somewhat related matter, do marine “cold snaps” resemble the antithesis of MHWs? I realize that what I am discussing here is treated in the present text in lines 235-254, but I think that treatment can be fleshed out, especially regarding atmosphere-ocean feedbacks. An exception here is ENSO; I do not feel that the authors need to belabor ENSO dynamics in the present paper.

The paper includes some material on our present limitations in predicting MHWs but again, perhaps some more details/examples can be covered without adding too much new material. I expect most readers would be interested in whether present predictions are limited more by lack of key observations or our modeling capabilities. Of course this is liable to be regionally-dependent, but perhaps there are studies available to be used as examples.

The effects of climate change on MHWs is an interesting subject, and the authors have an effective section of the paper devoted to the subject. It bears mentioning that there are some relevant papers (e.g., Schmeisser et al. ESS Open Archive, 2020; Qiu et al., DSR-II, 2021) that could be briefly summarized. Along the lines of an above comment, I feel that potential changes in atmosphere-ocean interactions could have important consequences for the nature and frequency of MHWs. Conversely, as mentioned in recent papers, the impacts of MHWs on the atmosphere (particularly boundary layer clouds), and for that matter, marine ecosystems may provide valuable lessons on probable changes accompanying the overall climate. The paper includes a brief statement on this matter in the last sentence of the Introduction, but it might be worthwhile to say a bit more on the subject, perhaps with a couple of examples.

MHWs are being recognized as potential sources of predictability for extended weather forecasts. NOAA/CPC incorporates information on anomalous SSTs in their 3-4 week forecasts for Hawaii, and ocean temperatures along the US west coast are being used in seasonal weather predictions for the Pacific Coast states, as indicated in recent seasonal prognostic discussions. Conceivably the authors should mention this growing practice.

A small point here: evaluation of sub-surface forecasts from J-SCOPE for the coastal waters of the Pacific Northwest indicate a modest level of skill above persistence (Siedlecki et al., 2016 and 2023). So I feel that line 434 may be overstating the case.

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Dear Dr Capotondi,

Your manuscript titled "A Global Overview of Marine Heatwaves in a Changing Climate" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Alireza Bahadori, PhD
Associate Editor
Communications Earth & Environment

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

I thank the authors for their detailed response to my comments. There are nor further modifications needed.

Reviewer #2 (Remarks to the Author):

I am of the opinion that this a valuable review of marine heat waves that will be of interest to the readers of Communications

Earth & Environment.

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Responses to Reviewer 1

This manuscript presents a review of recent advances on Marine Heatwave (MHW) research, with an emphasis on the study of three-dimensional structure of MHWs. Other topics covered in the review are compound events and biogeochemical extremes and predictability of MHWs. There are also sections focused on defining MHws and about MHWs in a changing climate.
Given the huge number of publications that are being produced nowadays around the important topic of MHWs, these review works are necessary in order to discern the main lines of emerging results that are otherwise scattered. I therefore commend the authors for this effort. The review is written clearly and concisely, although there could be a reorganization of some of the sections with similar topics. I am thinking about the sections "Defining a marine heatwave" and "Marine heatwaves in a changing climate", which could come one after the other in the text, as well as "Compound and cascading events" and "Prediction of MHWs and associated biogeochemical extremes".
We thank the reviewer for their positive and constructive comments.
The layout of the various sections emerged after careful considerations by our group regarding the content of each section and the overall paper structure. Since the influence of climate change on MHWs is a theme that is touched upon in several of the sections, as reflected in the title, it seemed appropriate to have a section summarizing the major aspects of this topic at the end of the paper, to lead the way to the "Summary and future perspectives". Concerning the "Prediction of MHWs and associated biogeochemical extremes" section, we see the reviewer's point about having that section after the section on "Compound events". However, since most prediction systems use climate models, discussing the performance of current climate models in the representation of MHWs seems preferable prior to discussing MHW prediction. For these reasons, we have decided to keep the current paper layout.

The observation of MHWs other than with satellite data remains difficult, as it happens with many events that can occur anytime, anywhere. Only institutions with a solid fleet of platforms (moored buoys, gliders, ship time etc.) can dedicate the needed effort to carefully study a MHW, as depicted in the example given in box 2, and which is out of reach of many institutions. Given that MHWs can occur anywhere, and have far-reaching and cascading impacts, there needs to be a concerted effort to improve our global capacity to measure MHWs and the state of the ocean in general, and not only at the surface. A better knowledge of the state of the ocean at depth, including for example a sustained effort at deploying Deep Argo floats, will form the basis for better models and forecasts, and will allow for the understanding of future changes.
We agree with the reviewer's assessment that to study phenomena that can occur anytime, anywhere more concerted efforts are needed to improve our global capacity to observe the ocean both at the surface and in the subsurface. We have a whole section dedicated to observations needed for MHW research. In this section, we highlight the "transformative capability provided by Argo floats", while also mentioning the caveats of these measurements, including, e.g., their limited temporal resolution (preventing MHW detection at daily timescales), and their limited ability to provide measurements near the coast, where MHWs may be more impactful on marine ecosystems and coastal communities. We also now emphasize in the "Summary and Future Perspective" section the need for concerted effort to measure the ocean and MHWs, using some of the language suggested by the reviewer:

"*Given that MHWs can occur anytime, anywhere, concerted efforts to improve our global capacity to observe the state of the ocean both at the surface and in the subsurface are needed to properly monitor MHWs and their cascading impacts, as well as to constrain ocean reanalyses and assess model performance. Sustained observations, both globally (e.g., satellite, (deep-)Argo) or regionally (e.g., moorings), in conjunction with ocean reanalyses and long time series from empirical models, are necessary to monitor long-term changes in ocean properties and robustly assess the statistics of extreme warm events relative to those long-term changes.*" (Lines 582-589)

Another topic that I think requires attention is the detection of past MHW events, in order to understand how their rate and intensity is changing. Past assessments at depth can only be done through the use of reanalyses, but there are several reanalyses that provide diverging results for the state of the ocean in the past decades. Any MHW study that uses reanalyses should be done with an informed choice on the options available, and this is even more true for any variable other than temperature (i.e. for compound events), where the divergence (uncertainty) among model estimates is far greater. The two above topics are, in my opinion, of great importance in MHW research, but are only briefly, if at all, mentioned in this work.

We have a paragraph discussing the use of reanalyses for MHW studies in the section on Observations. In this paragraph, we also point out some of the limitations that reanalyses have. In light of the reviewer's comment, we have modified the paragraph to also highlight the use of reanalyses to study past event, and to mention that they may differ among each other. The updated paragraph now reads: "*To overcome issues associated with sparse and inconsistent observations, and to extend the analysis of MHWs back to the pre-satellite era, many studies have leveraged ocean reanalyses—models constrained by observations through data assimilation— to understand MHW drivers and dynamical processes, and analyze MHW characteristics at both the ocean surface and in the subsurface. Ocean reanalyses offer uniform data coverage in time and space, in some cases at high-resolution (e.g., GLORYS12v1[1]), thus also facilitating the characterization of MHWs on continental shelves. Reanalysis products are subject to model errors and biases, and may differ in their representation of MHWs over past decades (e.g., Castillo-Trujillo, 2023). Thus, they should be used with care to study extremes, especially in areas where limited observations were assimilated (e.g., the deep ocean or shelf regions). Some variables, like biogeochemical properties, are significantly less constrained by observations than physical quantities like temperature."* (Lines 211-221)

Detailed comments:

The starting 2 sentences of the manuscript "Marine heatwaves (MHWs) have dramatically impacted marine ecosystems and ecosystem services over large areas of the world oceans. In this paper, we review the recent substantial advances in this active area of research" seem to say that the paper focuses on the impact of MHWs on the ecosystem, and not on MHWs at large, but the latter is true.

We agree with the Reviewer that the first sentence of the abstract seems to imply that the focus of the review paper will be primarily on impacts. Of course, impacts are an important motivation to study the dynamics and predictability of these extreme events. We have modified the first sentence as:" *Marine heatwaves (MHWs) have profoundly impacted marine ecosystems over large areas of*

the world oceans, calling for improved understanding of their dynamics and predictability." (Lines 52-53).

Lines 162 to 168: in addition to the spatial and temporal resolution of the satellite SST datasets, the quality of the interpolated datasets if one is using level-4 SST data also has to be considered, as it is the actual resolution (minimum scales resolved by the dataset) which often differ from pixel size in these L4 estimates.
This is a good point. To account for the reviewer's comment, we have modified the paragraph to say "*However, different datasets will have varying temporal and spatial resolutions, different interpolation accuracies, and/or may be sporadic and contain data gaps.*" (Lines 163-165)

Line 219: I was somehow surprised by the mention of paleoclimate proxies in this section. These estimates of past climate lack the temporal and spatial resolution to effectively study MHWs, which are per definition short and localised. Reference 88 deals with with a time series from 1800 to present, which I would not classify as paleo. Reference 89 is about the present-day effect of MHWs in foraminifera, which as noted by the authors lack the temporal resolution in paleo time series to study MHWs in the past.
There are ongoing efforts to use proxy data for this purpose, but we agree with the reviewer that their applicability for the study of MHWs is currently limited, primarily due to limited time resolution and spatial coverage. As a result, we have removed the paragraph on proxy data, which also helped manage the paper length.

Line 248-249: "Advection-driven MHWs typically have a smaller surface area, but last longer [21] and reach deeper [104]". Reference 104 looks at one case study in Eastern Australia, so the sentence before should be modulated (i.e. may reach deeper), or additional evidence should be provided to maintain the assertiveness of this sentence.
We agree with the reviewer. We have modified the text as suggested by the reviewer ("*they may reach deeper*"). (Lines 248-249)

Figure 2 shows a series of schemas on the evolution in time and space of MHWs, but some of them are perhaps too schematic, failing to show what the authors claim. For example, figure 2f is said to show Ekman pumping and effect of Rossby waves, and I fail to see any of these effects in this figure.
Panel 2f intends to show subsurface warming occurring as a result of vertical movements of the thermocline. This vertical movement may occur through localized Ekman pumping or through the passage of Rossby waves. Fig. 2f specifically illustrates, schematically, the Rossby wave passage. We have moved the reference to Fig. 2f immediately after mentioning Rossby wave passage to make a clearer connection to what is shown. (Line 294-295)

Figure 6 is said to show widespread ocean warming, result of heat absorbed by the ocean (line 476-477), but this figure shows projections of MHW changes in the coming decades.
The reviewer is right. We have changed the first sentence of the section on Marine heatwaves in a changing climate to be consistent with what is shown in Fig. 6a, as well as updating a reference: "*The ocean has stored more than 90% of the excess heat (Forster et al. 2024) that has accumulated in the Earth System due to human-induced increases in radiative forcing agents, resulting in ocean*

warming that is projected by climate models to become large and widespread by the end of the century (Fig. 6a)." (Lines 477-479)

Box 2. This box is mentioned in the text as "novel ideas for integrated observing systems". As far as I see it, this is a multiplatform study of a specific event, as there have been others to monitor for example, submesoscale variability in a region. But I fail to see what is novel with this approach, in the frame of MHW study. In addition, the data are shown, but there is no indication on how these data have helped monitor MHWs: maybe showing anomalies, or MHW status in the time series of panel e would be more adequate. A box showing the location of panel b should be included in panel a. What is the source of SST data in panel a? What do the Argo profiles show? Again, maybe anomalies should be shown in order to reinforce the value of these measures in the monitoring of MWHs. A useful discussion in this box would be how MHWs could be monitored using only partial observations. As I mentioned above, it is rare that such a vast amount of different data sources are available to everyone, and more often than not scientists have to perform their monitoring using only 1 or 2 of these kind of data, so what are the lessons learned from these exercises? What is the best strategy to monitor MHWs with few observations?

We agree with the reviewer's point about the novelty of the observing system displayed in Box 2. We mentioned "novel ideas" in the Summary and Future Perspectives section. We have modified that sentence to say: "*On the observational side, multi-platform systems capable of providing the three-dimensional structure of MHWs in near real-time are now emerging (Box 2).*" (Lines 536-538)

We have also modified the figure in Box 2, following the reviewer's suggestion. In panel a, we have adapted the original image of SST percentiles available through Australia's Integrated Marine Observing System (IMOS) OceanCurrent. This is the web platform that allows for accessible visualizations of marine heatwave detection around Australia and available near real time observations through IMOS. We have updated the colormap so that extremely warm areas are in dark red and we have enhanced the visibility of the data sources available in near real time at the peak of the event on 19 February.

While this example displays how multiple platforms can be used to monitor a specific event, these observational platforms and visualizations are available for temperature monitoring in the Great Barrier Reef and adjacent Coral Sea during other marine heatwaves as well. We further emphasize in Box 2 that the example displayed in the Box is just an illustration of the use of this multi-platform system.

Following the reviewer's suggestion, now the area displayed in panel b is indicated by a box in panel a, and the SST dataset used to produce panel a is indicated in the text. Please note that the SST dataset has been cited as IMOS2024a.

In panel c, we have modified the Argo temperature profiles so that they are shown as temperature anomalies for different days, based on the CSIRO Atlas of Regional Seas (CARS2009) temperature climatology (0.5° horizontal resolution). This climatology has been used to produce visualization of the near real time Argo temperature and salinity anomaly profiles displayed on IMOS OceanCurrent. The temperature climatology for each of the four days corresponded to the

same grid pixel but only varied subtly in time and so differences in the temperature climatology profiles are not evident in the left panel. The right panel illustrates how the Argo profiles revealed positive temperature anomalies near the surface but the vertical structure of anomalies varied considerably with depth, an aspect requiring further investigation for marine heatwaves detected at the surface.

In panel e, the near real time, near-surface temperature time series from the NRSYON mooring station had gaps in relatively recent data (from 2013, as now noted in the panel legend). So instead of constructing a climatology from a recent reference period and for consistency with panel a, we have included the night-time based, daily climatology from the SST Atlas of Australian Regional Seas (SSTAARS) at that location (red dashed line). We have also indicated the period corresponding to MHW conditions based on satellite imagery at this location, as the reviewer suggested. We have chosen to display the absolute temperatures rather than anomalies, as the seasonal cycle and the timing of the summer maximum is an important aspect for evaluating thermal stresses on marine ecosystems.

In terms of lessons learned, one of the transformative ways in which IMOS and AIMS, Australia's national tropical marine agency, has supported understanding of marine heatwaves is through long-term, sustained observations, critical for the definition of a climatology, and also, more recently, through rapid deployment of agile observing technologies (gliders) or simple temperature loggers. Such a rapid response to collect data is critical for informing stakeholders on the state of a marine heatwave so that in-water temperature observations can be linked with ecological impacts. Here we are trying to illustrate how a multi-platform and integrated system can be used to successfully monitor marine heatwaves in near real time. The need for both sustained observations and systems that can be rapidly deployed was already stressed in the "Summary and Future Perspectives" section.

Finally, we also agree with the reviewer about the importance of identifying the observations that are most essential to measure MHWs. In the "Summary and Future Perspectives" section we have added the sentence: "Such *multi-platform systems, however, may not be feasible everywhere. Assessing which observations can most effectively monitor MHWs in different regions is a critical issue that the MHW community must address*." (Lines 591-593)

Responses to Reviewer 2

I have a positive opinion of this paper. There have been previous reviews of marine heatwaves (MHWs), as noted on line 84, but the present paper represents a meaningful contribution to the growing body of work on the topic. It includes a wealth of references and clear writing. My comments that follow represent not serious concerns but rather thoughts for the authors to consider in revision, without making the paper too much longer.

We thank the reviewer for their positive and constructive evaluation of our paper.

I feel there should be greater recognition that the processes responsible for the onset of MHWs are not necessarily the same as those responsible for their maintenance. This can be especially the case for MHWs that persist over multiple seasons. For example, and at least at middle and higher latitudes, anomalous insolation tends to be a much more important driver in summer rather than winter. Schmeisser et al. (JGR, 2019) represents an example of a paper dealing with both the onset and maintenance phases of the NE Pacific MHW of 2014-2016. On a somewhat related matter, do marine "cold snaps" resemble the antithesis of MHWs? I realize that what I am discussing here is treated in the present text in lines 235-254, but I think that treatment can be fleshed out, especially regarding atmosphere-ocean feedbacks. An exception here is ENSO; I do not feel that the authors need to belabor ENSO dynamics in the present paper.

We thank the reviewer for bringing to our attention the processes that could contribute to the maintenance of the initial SST anomalies. This is indeed an important point. In response to the reviewer's comment, we have added a sentence at the end of the paragraph highlighted by the reviewer, where we state: "*Changes in atmospheric-ocean interactions, including positive cloud feedbacks (reduction of low-cloud cover leading to enhanced insolation), in response to the initial SST anomalies, may contribute to the maintenance and intensification of those anomalies, and increase their persistence, as documented for long-lasting events in the northeast Pacific (Myers et al. 2018; Schmeisser et al. 2019).*" (Lines 254-257)

We also note that marine "cold spells" were not discussed in the paper, as we decided to focus on warm extremes.

The paper includes some material on our present limitations in predicting MHWs but again, perhaps some more details/examples can be covered without adding too much new material. I expect most readers would be interested in whether present predictions are limited more by lack of key observations or our modeling capabilities. Of course this is liable to be regionally-dependent, but perhaps there are studies available to be used as examples.

There are many studies that have examined SST prediction, but fewer that have considered the prediction of the extreme SST values. For conciseness, we have discussed here the latter examples at a global scale. Regional studies are strongly affected by data used as boundary conditions and surface forcing, so making general statements on the predictability of events is difficult. However, the point raised by the reviewer, concerning the cause for limited prediction skill, is a very important one. In the context of global climate models, this issue mainly involves inherent predictability of the extreme SST anomalies vs. models' ability to properly capture the sources of that predictability. For example, in the Northeast Pacific, stochastic atmospheric forcing (the unpredictable part) seems to have significantly contributed to the onset of the Blob and controlled its initial amplitude, although large-scale modes of variability (like decadal variability and ENSO) appear to have promoted the development of the anomalies (Holbrook et al., 2019; Capotondi et al. 2022), and influenced their evolution and persistence (Di Lorenzo and Mantua, 2016; Xu et al. 2021). An important challenge in MHW prediction is to assess the predictable part, and ensure that models capture those drivers realistically. The need to assess models' ability to capture the relevant processes in the context of MHW prediction and projection is highlighted in the Summary and Future Perspectives section. (Lines 548-559)

The effects of climate change on MHWs is an interesting subject, and the authors have an effective section of the paper devoted to the subject. It bears mentioning that there are some relevant papers (e.g., Schmeisser et al. ESS Open Archive, 2020; Qiu et al., DSR-II, 2021) that could be briefly

summarized. Along the lines of an above comment, I feel that potential changes in atmosphere-ocean interactions could have important consequences for the nature and frequency of MHWs. Conversely, as mentioned in recent papers, the impacts of MHWs on the atmosphere (particularly boundary layer clouds), and for that matter, marine ecosystems may provide valuable lessons on probable changes accompanying the overall climate. The paper includes a brief statement on this matter in the last sentence of the Introduction, but it might be worthwhile to say a bit more on the subject, perhaps with a couple of examples.

Thanks for raising this issue. We briefly (due to word limit constraints) mention the possible influence of MHWs on cloud feedbacks toward the end of the "Summary and Future Perspectives" section, suggesting the importance of exploring the possible influence of MHWs on the Earth's radiation budget (Lines 577-578). We have added the reference to Schmeisser et al. (2019), as suggested by the reviewer. However, since Schmeisser et al. (2020) is a preprint from four years ago, and is not peer-reviewed, we did not include it. Qiu et al. (2021) seems to be primarily focused on the representation of MHWs in CMIP models and future changes in basic MHW metrics. We have added the Qiu et al. (2021) reference in the section on "Climate models representation of MHWs". (Line 379)

MHWs are being recognized as potential sources of predictability for extended weather forecasts. NOAA/CPC incorporates information on anomalous SSTs in their 3-4 week forecasts for Hawaii, and ocean temperatures along the US west coast are being used in seasonal weather predictions for the Pacific Coast states, as indicated in recent seasonal prognostic discussions. Conceivably the authors should mention this growing practice.

SST anomalies are clearly important for subseasonal forecasts. In particular, SST anomalies in the tropical Pacific, especially those related to ENSO (whose positive phase can be viewed as a MHW) have always provided an important source of predictability for US West Coast conditions. However, it is not clear how MHWs in other regions can affect week 3-4 forecasts, and whether other agencies exploit SST anomalies related to MHWs for their forecasts. We found it hard to include such information, without proper citation, in the context of this paper, also considering the space limitations. Thus, we have not included the reviewer's suggestion.

A small point here: evaluation of sub-surface forecasts from J-SCOPE for the coastal waters of the Pacific Northwest indicate a modest level of skill above persistence (Siedlecki et al., 2016 and 2023). So I feel that line 434 may be overstating the case.

We thank the reviewer for this comment. In this section, we specifically focus on the prediction of extremes. In the line 434 of the original manuscript highlighted by the reviewer, we made a general statement about prediction skill of subsurface MHWs globally ("*subsurface skill outside the tropics is primarily due to persistence*"). Here, "primarily" implies that this is not necessarily true everywhere, but in some areas, prediction skill may exceed persistence. This can be expected to be especially true for modeling efforts focusing over a small region and heavily constrained by observations, like J-SCOPE.

We thank both anonymous reviewers for their final positive comments and for accepting our manuscript.