

Reviewer 2

General comments

This study provides a comprehensive assessment of the characteristics and drivers of marine heatwaves (MHWs) in the central South Pacific, in particular across the archipelagos of French Polynesia (FP). The authors use sea surface temperature observations for the period 1981-2024 to assess MHW metrics (frequency, duration, intensity) over FP, as well as their relations to ENSO and various ENSO flavors. An ocean reanalysis product for the period 1993-2024 is used to classify MHWs into types according to their main physical driver (e.g., air-sea heat flux or horizontal advection), and to investigate the relationship of mixed layer depth, wind stress, and sea surface height to ENSO and MHW occurrence.

Overall, this study provides a very thorough and comprehensive analysis of MHWs in the central South Pacific, which will be useful to regional stakeholders as well as to the broader research community working on MHWs at regional scales. The results are novel, the methods are clearly defined, and the presentation is easy to follow.

I recommend this manuscript for publication after the minor comments below have been addressed.

We gratefully thank the reviewer for his comments and corrections, which have improved the manuscript. Please find below our point-by-point responses to the reviewer's comments. The authors' responses are shown in blue.

Specific comments

Ln. 23: "FP": define abbreviation on first use

We thank the reviewer for noting that issue. We have now introduced the full name "French Polynesia" at the beginning of the abstract.

Ln. 29: "This modulation arises from...": during which ENSO phase (El Niño or La Niña)?

This applies to both El Niño and La Niña; however, the regions affected differ between the two phases. The original statement was intended as a general description of ENSO modulation. We have now clarified this point in the manuscript as follows: "This modulation arises from reduced wind-evaporation cooling with reduced wind speed, shoaled mixed layers, and enhanced horizontal heat advection, occurring primarily to the northeast of French Polynesia during El Niño and to the southwest during La Niña."

Ln. 36: include another reference for future MHW projections (Oliver et al. 2018 is about MHWs in the past)

We've added Oliver et al., 2019.

Ln. 33-56: the terms frequency, occurrence, and likelihood seem to be used interchangeably for the same concept (e.g., Ln. 35, 43, 45, 47). It could be useful to harmonize the terminology in order to clarify that the same thing is meant in each context

We modified accordingly by changing ‘likelihood’ by ‘frequency’.

Ln. 55: “This highlights the need for regional studies...”: it also motivates the need for observation-based studies, as in this manuscript

We’ve added this statement:

« This highlights the need for regional studies and observation-based studies to better understand MHWs »

Ln. 80: “Data and model simulations”: since no model simulations were performed for this study, the section could be called “Observational and reanalysis data” or similar

We’ve changed the title of the section accordingly.

Ln. 128-133: It would be good to motivate the choice of this particular method to quantify cumulative heat stress

We agree with the reviewer’s comment. We’ve added the justification that this metric is widely used : “In order to quantify the variability of the cumulative heat stress felt by the marine ecosystems, the daily Degree-Heating Weeks (DHW), **commonly employed in coral bleaching risk assessments**, were computed for each austral summer from 1981 to 2024 following Skirving et al., (2020).”

Ln. 154: “N phases”: define this (neural phases)

Done

Ln. 195: “separately as well as their sum”: is this criterion also used for Q-MHW and HADV-MHW?

No this criteria is not applied for Q-MHWs and HADV-MHWs.

Ln. 194-197: does this classification assign every MHW to one of the categories, or does it leave out any events?

Events for which none of the three terms in the heat budget equation were positive during MHW’s onset were excluded from the analysis and assigned to the class “NOT DEFINED.” These represented only a small number of cases. Figure R1 shows the proportion of events attributed to all classes including MIXED and NOT DEFINED MHWs:

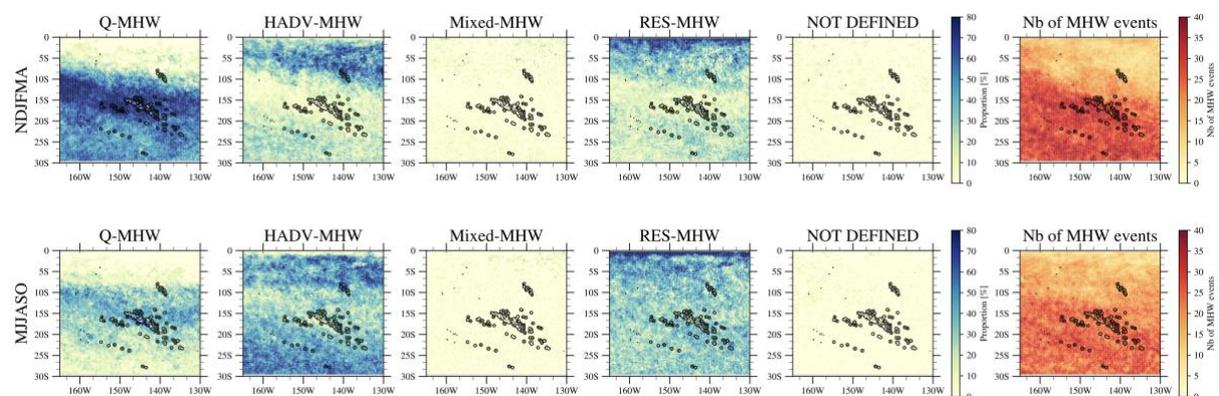


Figure R1: Same as Fig. 6 but including Mixed-MHWs and NOT DEFINED MHWs.

We have added a sentence about that in the text:

“For only a few events, none of the three terms on the right-hand side of Eq. (3) acted as positive drivers during MHW onset. These events were therefore excluded from the analysis. »

Ln. 202: “all MHWs [...] were used”: is this not a contradiction with the previous sentence? We thank the reviewer for this question, which highlighted a lack of clarity in the sentence. We have rephrased it as follows:

« These averages were computed separately for each MHW type during the development phase, defined as the period from MHW onset to its peak intensity. During the decay phase, defined as the period from the peak to the end time, composites were constructed using all MHWs, including HADV, Q, and RES-MHWs.”

Ln. 213: why are there “fewer MHW days” in the cold season compared to the warm season, is this because of the minimum duration of 5 days?

Yes indeed. Here, MHW days are defined as days for which SST exceeds the 90th-percentile threshold (SST^{90th}) and when this condition persists for at least five consecutive days. This duration criterion explains why the number of MHW days is not exactly 10% of the total number of days. Among all days exceeding the SST^{90th} threshold, the fraction that satisfies the five-day persistence requirement varies depending on atmospheric conditions (e.g., wind, air–sea fluxes) and oceanic conditions (e.g., mixed-layer depth, heat advection) that vary in space and according to the season.

Ln. 241: “In the Austral islands, MHWs happen more regularly each year, with some bigger peaks”: this is imprecise wording, it is not clear what is meant by “regularly” (more even gaps? More frequent? What is the quantitative meaning of “some bigger peaks”?)

We have rephrased it more clearly and have replaced “regularly” by “more frequently each year”:

“In the Austral Islands, MHWs are occurring more frequently each year, although substantial interannual variability remains, with some years—such as 2021 and 2022—characterized by a high number of MHW days.”

General: I recommend to avoid using the jet/rainbow colormap (e.g. in Figs. 1, 4, 6, etc.), see e.g. <https://doi.org/10.5194/hess-25-4549-2021>

We thank the reviewer for this comment. We have modified the different figures accordingly by choosing sequential colormaps.

Ln. 247: “the gray dashed areas”: these areas are not clearly visible. Maybe if a different colormap is used (as suggested above), the areas will become more visible. If not, perhaps an extra figure showing only the general study area as well as the archipelagos and their names could be useful (e.g. as a new Fig. 1).

We have changed their color to black, which makes these areas more visible with the revised colormap. We thank the reviewer for pointing out this issue.

Fig. 2: In the legend, spell out “warm season” and “cold season” (“warm” and “cold” could be taken to mean warm/cold extremes at first glance). In panel b, why are the mean values not

given as in the other panels? In all panels, the mean values are not clearly legible. The colors for Gambier and Austral are hard to distinguish

We thank the reviewer for these comments on Fig. 2. We have modified the legend accordingly. The mean values in panel b are not shown because the spread between the mean and the median values in maximum intensity, when expressed in absolute values, is small and difficult to distinguish visually; this information can instead be assessed in panel a, where values are expressed as anomalies relative to climatology. We have clarified this point in the figure caption:

“In panel b, the mean value is not shown because it is very close to the median, and displaying both would reduce the readability of the plot. The difference between the mean and median maximum intensity can be assessed in panel a.”

We have also revised the colors associated with the archipelagos to improve visual distinction.

Ln. 256: “The slope of the gray dashed line...”: it would be useful to test the statistical significance of these trends

We thank the reviewer for this comment. The significance, assessed by the p-values are:

Marquises $p=0.26$

Gambier $p=0.0013$

Archipel des Tuamotu $p=0.003$

Archipel des Australes $p<10^{-6}$

Archipel de la Société $p<10^{-5}$

The trend for the Marquesas is therefore not statistically significant at the 99% confidence level, whereas those for the other archipelagos are.

For the trend of the area covered by a MHW over FP the p-value is $< 10^{-6}$.

We've added that information in the caption of Figure 2 and S6:

« The estimated trend slopes expressed in MHW days per decade are $6.1 \text{ day.decade}^{-1}$ for the Marquesas ($p = 0.26$), $8.6 \text{ day.decade}^{-1}$ for the Gambier ($p = 0.001$), $8.5 \text{ day.decade}^{-1}$ for the Tuamotu ($p = 0.002$), $13.9 \text{ day.decade}^{-1}$ for the Austral Islands ($p < 10^{-6}$), and $10.2 \text{ day.decade}^{-1}$ for the Society Islands ($p < 10^{-5}$). »

“In panel e, the trends for the number of MHW days per year are no longer statistically significant with $p_values > 0.15$. The estimated trend slopes expressed in **MHW days** per decade are $7.9 \text{ day.decade}^{-1}$ for the Marquesas ($p = 0.15$), $-1.8 \text{ day.decade}^{-1}$ for the Gambier ($p = 0.53$), $-0.7 \text{ day.decade}^{-1}$ for the Tuamotu ($p = 0.77$), $0.01 \text{ day.decade}^{-1}$ for the Austral Islands ($p > 0.99$), and $-3.0 \text{ day.decade}^{-1}$ for the Society Islands ($p > 0.19$). For the daily proportion of FP in MHW the slope is $0.003 \text{ day.decade}^{-1}$ ($p<10^{-7}$).”

Fig. 3: what do the errorbars in panel d) quantify?

We have added that to the caption of Fig. 3: “Black error bars indicate the spatial standard deviation of the statistics calculated across grid points associated with each archipelago area (black dashed outlines in panel e).”

Ln. 590: "Our analysis gives confidence in GLORYS, to study [the] vertical extent of MHW[s].":
how does this follow from the analysis?

We meant that the overall agreement between GLORYS and OISST in terms of MHW detection statistics provides confidence in the ability of GLORYS to investigate MHW characteristics, including their vertical extent. However, we did not perform any analysis on the vertical extent of MHWs in this study.

Ln. 599: "TCs": define abbreviation

Done

Technical corrections

Ln. 17: "of world's" -> of the world's

We have deleted this sentence during the reviewing process

Ln. 23: "most of MHWs" -> most MHWs

Done

Ln. 25: "reduce" -> "reduces"

Done

Ln. 33: "Marine heatwaves (MHWs), known as...": it should be the other way around (XYZ events are known as MHWs)

Done

Ln. 40: "...driving the MHWs" -> specify "driving MHWs over FP"

Done

Ln. 42: "are known to be important drivers" -> is known to be an important driver (referring to ENSO)

Done

Ln. 45: remove stray parenthesis "("

Done

Ln. 47: "intensity occurrence" -> intensity and occurrence? (or: intensity and frequency)

Yes, it is "intensity and frequency »

Ln. 54: "due to the resolution or not of...": improve phrasing

We have rephrased the sentence as follows:

« The dominant mechanisms during the MHWs' onset and decay are region dependent (Elzahaby et al., 2022; Bian et al., 2023) and also depend on the spatial resolution of the model, which controls its ability to resolve oceanic eddies (Bian et al., 2024).»

Ln. 59: “due to FP geographical position”: due to FP’s ...

Done

Ln. 60: “ENSO SST anomalies edges”: this is unclear

We clarified this sentence as:

“Opposite influences across different parts of the country are observed depending on the ENSO flavor, due to FP’s geographical position often near the transition zone where ENSO SST anomalies change sign and its effect on the South Pacific Convergence Zone (SPCZ) position »

Ln. 60: “its effect”: specify the effect of what (ENSO?)

We have specified it as: “Opposite influences across different parts of the country are observed depending on the ENSO flavor, due to FP’s geographical position often near the transition zone where ENSO SST anomalies change sign and ENSO non-linear effect on the South Pacific Convergence Zone (SPCZ) position »

Ln. 107: “were computed” -> was computed

Done

Ln. 111-113: the “number of events” and “gaps between events” are not really metrics for “each MHW”

We thank the reviewer for highlighting that issue. We separated these two metrics from the others: “These include the maximum, mean, and cumulative intensity, duration, onset and decline rates (defined as the mean SST change from start to peak and from peak to end, respectively). The number of events and the gaps between events were also computed”

Ln. 112: “SST change from start to peak”: is this the rate of change (in K/day) or really just the change (which would be equivalent to the intensity)?

It is indeed the rate of change. We added this to the text: “(defined as the mean SST rate of change from start to peak and from peak to end, respectively)”.

Ln. 113: “MHW intensity can be expressed either...”: so which option did you choose?

We chose both actually. The formulation may be misleading we agree with the reviewer’s comment. We rephrased as: “MHW intensity were expressed either in absolute terms (i.e., the actual SST) or relative to the mean climatological baseline. »

Ln. 118: “In the various sections”: sections of the manuscript, or geographical/time sections? If the former, it may not be necessary to specify this

It stands for the sections of the manuscript. We have specified: « Throughout the manuscript, a distinction was made between MHWs occurring during the austral winter and those occurring during the austral summer, according to the date of their peak intensity. »

Ln. 124: “cooler-than-average SST climatology” -> SST cooler than the climatology

Done

Ln. 136: It would be preferable to add an entry in the reference list for the cited website (including date of last access, etc.) and then citing it here. Also, mention what this data source is (“based on the French government’s XYZ”?)

We thank the reviewer for this suggestion. We added a proper reference entry for the dataset, including the date of last access, and clarified in the manuscript that this dataset corresponds to the official administrative geographic dataset for French Polynesia provided by the French government.

Ln. 138: “Whether or not...”: the wording should be changed as this structure makes the sentence difficult to parse. E.g., you can simply start the sentence with “Removing a long term temperature trend...”

We followed the reviewer’s suggestion, we started the sentence with “Removing a long-term temperature trend...”

Ln. 175: “Qnet”: check formatting

Done

Ln. 191: move the first minus sign on the RHS outside of the integral, specify which terms depend on the integration variable k , and maybe use a different symbol for the integration variable (e.g. t' instead of k , as it represents time)

We thank the reviewer for suggesting these modifications. We followed them in the manuscript. However as $'$ is already used in the equation we used “ $d\tilde{t}$ ”.

Ln. 215: “median values” -> median maximum intensity values

Done

Ln. 220: “are found” -> is found

Done

Ln. 238: “MHWs occurrence vary” -> MHW occurrence varies

Done

Ln. 250: “see map on the right”: there is no map

This was an error in the manuscript, which has now been corrected. We thank the reviewer for pointing out this issue.

Ln. 265: “1M km²” -> 10⁶ km²

Done

Ln. 267: Equivalent analyses of that...” -> equivalent analyses to those

Done

Ln. 272: “that region”: what region?

It is for French Polynesia. We specified that: “For the FP region ...”.

Ln. 279: “EN, LN or N conditions”: it could be useful to remind the reader of the meaning of these abbreviations

Done

Ln. 280: "using Pagli..." -> using the Pagli...

Done

Ln. 335: "MMM": what does this stand for?

MMM stands for « Maximum Monthly Mean (MMM)». We now remind in the caption the meaning of MMM.

Ln. 365: close the parenthesis

Done

Ln. 366: "year": remove

Done

Ln. 380: "in surface": at the surface

Done

Ln. 388: "firstly": mainly?

Done

Ln. 398: "flux-driven": does this refer to air-sea heat flux?

Yes it is. We rephrased as: "During austral summer, MHWs are primarily driven by air/sea fluxes in most ..."

Ln. 425: "averaged across": there is a word missing here

We thank the reviewer for noting that. We rephrased as: "In each panel, the composite represents the average across all MHWs of the corresponding type (Q-MHW or HADV-MHW) detected at each grid point."

Ln. 439: "reinforces" -> reinforce

Done

Ln. 464: "smooth out eddies pattern" -> smooths out eddy patterns

Done

Ln. 473: "present" -> presents

Done

Ln. 474: "hardly interpretable" -> hard to interpret?

Done

Ln. 498: "back to normal" -> neutral/zero

We chose "neutral".

Ln. 509: "to represent them": remove

Done

Ln. 523: "and may also reduce" -> and potentially also reducing

Done

Ln. 572: “the most extreme events”: globally?

We aimed at highlighting that, when focusing on the French Polynesia region in the global-scale analysis of Marin et al. (2022), the dominant mechanisms driving the most extreme MHWs are similar to those identified in this study. We clarified the text as:

« It is interesting to note that the conclusions obtained here about the mechanisms of all MHWs in FP correspond to that obtained by looking at the most extreme events over the region in the global-scale study of Marin et al., (2022) (their Fig. 3 and 4). »

Ln. 600: “intra-seasonal, variability”: remove comma

Done

Ln. 626: “relating the” -> relating to the

We rephrased as : “Accordingly, Fig. 5 quantitative results should not be read as direct indicator of coral bleaching; “

Ln. 632: “While OISST dataset” -> while the OISST dataset

Done

Ln. 633: “some MHWs commonly used metrics” -> some commonly used MHW metrics

Done.

We also added a new reference related to that statement: “(Chevillard et al., 2025)”. The text is now:

“While the OISST dataset has been shown to be well-suited for the analysis carried out in this study (Gupta and Sil 2024), differences between SST products can be significant for some commonly used MHW metrics (Chevillard et al., 2025) and this should be kept in mind. »

Fig. S1: the colorbar label should be degrees C, not “thresh”

We thank the reviewer for this comment. Figure S1 has been modified accordingly.

References

Oliver, E. C. J., Burrows, M. T., Donat, M. G., Sen Gupta, A., Alexander, L. V., Perkins-Kirkpatrick, S. E., Benthuisen, J. A., Hobday, A. J., Holbrook, N. J., Moore, P. J., Thomsen, M. S., Wernberg, T., and Smale, D. A.: Projected Marine Heatwaves in the 21st Century and the Potential for Ecological Impact, *Front. Mar. Sci.*, 6, 2019.

Chevillard, C., Le Gendre, R., Menkes, C., Izumo, T., Pagli, B., Van Wynsberge, S., and Cravatte, S.: Sensitivity of marine heatwaves metrics to SST products, focusing on the Tropical Pacific, *EGUsphere*, 1–36, <https://doi.org/10.5194/egusphere-2025-5417>, 2025.